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THE ESSENTIALS OF
BOTANY

BY

CHARLES E. BESSEY, M.SC., PH.D.

Professor of Botany in the Iowa Agricultural College; Late Lecturer
in the University of California; Associate Editor of the
"AMERICAN NATURALIST" (*Department of*
Botany)

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PREFACE.

In preparing this Briefer Edition the attempt has been made to present the essentials of modern botany in considerably less difficult language than has hitherto been usual in books of this grade. Many of the terms now in general use in the larger works are here anglicized, while English names have very generally been given for plants and plant-groups.

The sequence of topics and the general mode of treatment pursued in my larger work published in 1880 are here followed, with such changes and modifications as are demanded by the progress of the science since the original manuscript left my hands. In many cases the paragraphs have been carefully revised, while in others they have been entirely re-written.

I have thought it advisable to use the terms Zygophyta, Oöphyta, and Carpophyta, first proposed in the American Naturalist in 1882 (Vol. XVI. p. 46), for the second, third, and fourth Branches of the Vegetable Kingdom. This has been done for the sake of securing uniformity in nomenclature, as well as on account of the readiness with which the new terms take the English form: thus we may now speak of zygophytes, oöphytes, and carpophytes, as well as of protophytes, bryophytes, etc.

In its use I would beg the teacher to bear in mind that the book is intended to be merely *the guide*, and that a simple conning and recitation of its pages will give but a poor return indeed. Every effort should be made to have the pupil see things for himself. To aid him in this, numerous "practical studies" are introduced after the principal topics, and it is urged upon teacher and pupil that as much use be made of them as possible. Indeed, it would be an excellent plan to use the "studies" alone as a guide in a course of practical work.

C. E. B.

BOTANICAL LABORATORY,
IOWA AGRICULTURAL COLLEGE,
AMES, IOWA, July 8, 1884.

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BOTANY.

CHAPTER I.

PROTOPLASM AND PLANT-CELLS.

1. **Protoplasm.**—The living part of every plant is a softish, almost transparent substance called protoplasm. It may be seen in ordinary plants by making thin slices of the rapidly growing parts, and then magnifying them under a good microscope. Such a specimen is made up almost wholly of protoplasm. (Fig. 1.)

2. Although protoplasm is so abundant, its exact chemical composition is not known. It appears to be a mixture of several chemical compounds, and contains carbon, hydrogen, oxygen, nitrogen, sulphur, besides others of less importance. Nitrogen is always present.

3. When protoplasm is examined under a high magnifying power it generally appears to be somewhat granular. There may often be distinguished a clear transparent non-granular part making up the body of the protoplasm, and in this the granules are imbedded.

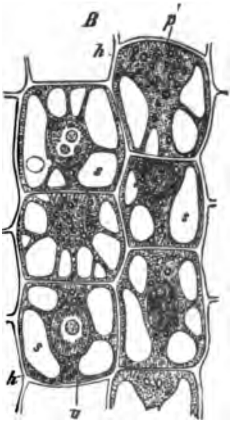


FIG. 1.—A few young cells from the root of Crown Imperial, showing protoplasm (*p*), vacuoles (*s*), and thin cell-walls (*h*). Magnified 550 times.

4. Living protoplasm possesses the power of imbibing food in the condition of watery solutions. The water with which plants are supplied in nature always contains a considerable amount of soluble matter, most of which is good food for protoplasm. The imbibition of watery food increases the size of the protoplasm, and this is one of the causes of growth in plants. Commonly there is a surplus of imbibed material, and this is stored in the protoplasm in the form of drops of greater or less size (the so-called *vacuoles*), thus adding still more to the distension of the protoplasm mass. (Fig. 1, *s*.)

5. The most remarkable property of protoplasm is its power of moving. Every mass of living protoplasm appears from observation to have the power under favorable conditions of changing its form, shifting the positions of its several parts, and in many instances of moving bodily from place to place. That these movements are so generally overlooked is due to the fact that in most cases they require the aid of a good microscope, but with such an instrument the student may find evidences of motion in the protoplasm of every plant.

6. The imbibition of food, and the various movements, are affected by the temperature of the protoplasm. They take place best in temperatures ranging from that of an ordinary living-room to that of a hot summer day (20° to 35° C. = 68° to 95° Fahr.). A sudden change of temperature of even a few degrees will at once check or stop both imbibition and movement; even a sudden jarring will for a time stop both kinds of activity.

Practical Studies.—In the study of protoplasm it is necessary to be provided with a compound microscope. For convenience of working, as well as for economy, the small instruments with short tube, allowing easy use in a vertical position, are much to be preferred. The most serviceable objectives are the ¼ and ⅛ inch, giving magnifying powers of from about 100 to 500 diameters. Such a microscope may be purchased in this country for from $30 to $40, and in Europe for somewhat less. A scalpel or good razor is useful in making sections. For the beginner the only reagents necessary are, 1, a solution of iodine (that made by first dissolving a very little potassic iodide in pure water and then adding iodine is the best for common use); 2, a solution of caustic potash in pure water (potassic hydrate); 3, alcohol; 4, some staining fluid, as magenta or carmine (common carmine ink is often quite satisfactory); 5, glycerine.

(*a*) Make very thin longitudinal sections of the tips of the larger roots of Indian corn (Fig. 2); stain some with iodine, which will turn the protoplasm brown or yellowish brown; stain others with carmine; examine by the aid of the ⅛-inch objective. Make similar sections of the tip of a young shoot of the asparagus.

(*b*) Make successive cross-sections of the root of Indian corn, beginning with the tip and receding five to ten centimetres. Note the vacuoles and use iodine and carmine. Make similar sections of young asparagus-stem.

(*c*) Make a longitudinal section of the young part of a verbena-stem in such a manner as to leave on each margin a fringe of uninjured hairs. Mount carefully in pure water. Examine at a high temperature (about 30° C. = 86° Fahr.) for a streaming motion of the protoplasm in the hairs. Place the specimen upon a block of ice, and note that the movement ceases. Warm again, etc.

(*d*) With similar specimens observe the effect of (1) iodine, which kills and stains the protoplasm; (2) alcohol, which kills and coagulates it; (3) glycerine, which withdraws water from it, and so collapses it.

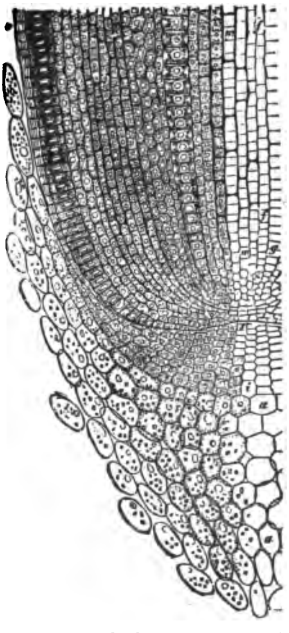


FIG. 2.—A little more than half of a longitudinal section of the tip of a young root of the Indian Corn. The part above *s* is the body of the root, that below it is the root-cap; *v*. thick outer wall of the epidermis; *m*, young pith-cells; *f*, young wood-cells; *g*, a young vessel; *s*, *i*, inner younger part of root-cap; *a*, *a*, outer older part of root-cap.

(*e*) Mount carefully in pure water a piece (2 to 4 centimetres) of one of the young "silks" of Indian corn. The movement is well seen in the long cells. Repeat the foregoing experiments.

(*f*) The following may be taken also, viz.: the stamen hairs of Spiderwort, the epidermis of Live-for-ever leaf, fresh specimens of the Stoneworts (Chara and Nitella), Eel-grass, etc.

7. **The Plant-Cell.**—In all common plants the protoplasm is found in little masses of definite shapes, each one enclosed in a little box (Fig. 1). The substance of these boxes was made by the protoplasm, somewhat as the snail makes its shell. Each mass of protoplasm with its box is called a Plant-cell, and the sides of the box are called the walls of the cell, or the cell-wall.

8. The cell-wall is composed of carbon, hydrogen, and oxygen ($C_{12}H_{20}O_{10}$), and has been named cellulose. At first it is very thin, but as the protoplasm grows older it thickens its wall by continually adding new material to it, so that at last it may be more than a hundred times as thick as at the beginning.

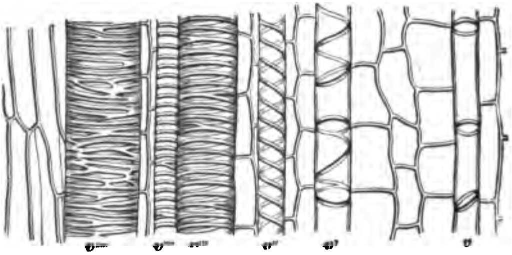


FIG. 3.—Longitudinal section of a portion of the stem of Garden Balsam. v, annular vessel; v', a vessel with thickenings which are partly spiral and partly annular; v'', v''', v'''', several varieties of spiral vessels; v''''', a reticulated vessel.

9. The cell-wall may be thickened uniformly, or, as more frequently happens, some portions may be much more thickened than others. When it is uniform the wall shows

no markings of any kind, but when otherwise it shows dots, pits, rings, spirals, reticulations, etc. etc. (Fig. 3). This thickening gives strength to the cell-wall, and serves either to protect the protoplasm, as in many spores and pollen-grains, or to help in building up the framework of the plant.

10. In some part of the protoplasm of each cell (often in the centre) there may generally be seen a rounded body composed of denser protoplasm (Fig. 1). This has been named the nucleus. It has been shown not to differ in any essential particular except in density from ordinary protoplasm. Its function is not certainly known.

11. Cells in plants are of various sizes and shapes. The largest (with a few exceptions) are scarcely visible to the naked eye, while the smallest tax the highest powers of the best microscopes. Cells which exist by themselves, as in many microscopic water-plants, are more or less spherical; so, too, are many spores and pollen-cells, and the cells of many ripe fruits where, in the process of ripening, the cells have separated from each other. Ordinarily, however, the cells are of irregular shapes, on account of their mutual pressure. Occasionally they are cubical, rarely they are regular twelve-sided figures (dodecahedra), but more commonly they are irregular polyhedra.

12. In a few plants, as the Slime-Moulds, the protoplasm has no definite size or shape; it may be of microscopic size, or it may form irregular masses as large as one's hand. Such plants are not composed of cells. They are nothing more than masses of shapeless protoplasm, and are among the lowest of all living organisms. In all other cases, however, the cell is the unit out of which the plant is composed, and in the study of different plants, no matter how much

they may differ in external appearance, we shall always find that they are made up of cells alike in all essential features. Thus the simple Green Slime of the rocks is composed of a single cell, the homologue of which is repeated millions of times in the giant oak of the forests.

Practical Studies.—(*a*) Mount a leaf of a moss for a good example of cells showing their walls. The sections of root-tips previously mentioned (p. 3) may be studied again with profit.

(*b*) For thickened cell-walls make sections of the shell of the hickory-nut or cocoa-nut.

(*c*) Make longitudinal and also cross sections of apple-twigs; some of the pith-cells show thickened walls marked by dots and pits.

(*d*) Make longitudinal sections of a stem of Indian corn, so as to obtain very thin slices of some of the threads which run lengthwise through it. Cell-walls showing rings, spirals, and reticulations may be readily found (Fig. 3).

(*e*) Mount spores of the "black rust" of wheat or oats (by carefully scraping off one of the blackish spots on the stem or leaves) for examples of thickened cell-wall for protection.

(*f*) Mount pollen-grains of mallows or squashes for thickened wall which has developed projections externally.

(*g*) Make longitudinal sections of the young part of a root or stem, stain with carmine, and after a little time note that the nucleus shows distinctly in each cell.

(*h*) For large cells examine the parts (leaves and stems) of water-plants. In the Water-net (Hydrodictyon) they may be seen with the naked eye.

(*i*) For very small cells mount a minute drop of putrid water and examine with the highest power of the microscope available. Myriads of minute cells, each a single plant, will be seen darting hither and thither in the water. These are the Bacteria, to be more fully noticed in Chapter VII. A tumbler in which leaves and twigs have been allowed to begin to decay will furnish good material.

(*j*) Slime-Moulds may frequently be found on rotten logs, on decaying planks of wooden walks, or on the "spent bark" of tan-yards. The common one is a yellowish mass, often ten to twenty centimetres long.

(*k*) For Green Slime scrape off a little of the green slimy growth to be found on damp walls, rocks, etc. Under a high power many little green balls of protoplasm may be observed. Each has a cell-wall.

13. **How New Cells are Formed.**—Most plant-cells in some stage of their growth are capable of producing new cells. This power is mostly confined to their early thin-walled state, new cells being rarely formed after the walls have attained any considerable thickness. There are two general methods, viz., (1) by the Division of cells, (2) by the Union of cells.

14. In the Division of a cell it may simply constrict its sides so as to pinch itself into two parts. In other cases the protoplasm first divides itself through the middle, and the two halves then help to form a partition-wall of cellulose between them. Both of these modes of division are known as Fission.

15. In some cases of Division the protoplasm divides itself into two, four, or many parts, which then become spherical in shape. Each part then covers itself with a cell-wall of its own; and the old cell-wall of the original cell, not being of further use, soon decays or breaks away. This kind of Division is known as Internal Cell-formation.

16. Cell-division always results in an increase in the number of cells, and is the usual process by which plants are increased in size, and in the number of their cells. Growth may be very rapid, even where the cells simply divide successively into two. Thus a single cell may give rise in its first division to two cells, next to four, then eight, then sixteen, thirty-two, sixty-four, etc. etc. By the twentieth division the cells would exceed a million in number.

17. The process of cell-formation by Union is exactly opposite to that by Division. Two cells which were separate unite their protoplasm into one mass, which then forms a cell-wall around itself. Thus instead of doubling the number of cells at every step, there is here an actual

decrease, and every time the process occurs there the result is but half as many cells as before.

Practical Studies.—(*a*) Carefully scrape off (after moistening with a drop of alcohol) a little of the white, mouldy growth on lilac-leaves, known as Lilac Blight; mount it in water, adding a very little potassic hydrate. Some of the threads will show the formation of new cells (spores in this case) by fission. Other kinds of blights, as for example that on grass leaves or that common on the leaves of cherry-sprouts, furnish equally good examples. (See Fig. 79, p.156)

(*b*) Strip off carefully a bit of the epidermis (skin) of a young Live-for-ever leaf, and mount it in water. By careful examination some of the cells may be observed with very thin partition-walls formed across them. The new walls can be distinguished from the older ones by their thinness.

(*c*) Mount a very small drop of yeast in water and observe in the yeast-plants that modification of fission which is called budding. Each yeast-plant is a minute oval cell; it first pushes out a little protrusion which becomes larger and larger, finally equalling the first. In the mean time a partition forms between the two, which then separate from one another. (Fig 4, *a* and *b*.)

(*d*) Grow some yeast for a few days under a bell-jar on a moist slab of plaster, a cut potato or carrot, or even a bit of moist brown paper. Upon examining some such yeast it will be found that some of the cells contain several little new cells, formed by internal cell-division. (Fig. 4, *c* and *d*.)

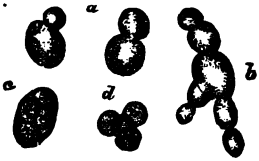


FIG. 4.—Yeast-plants reproducing by division: *a* and *b* by budding; *c* and *d* by internal cell-division. Highly magnified.

(*e*) Make very thin cross-sections of young flower-buds so as to cut through the stamens. If the specimen is of the proper age, certain cells may be seen to have divided internally into four parts, each of which subsequently becomes a pollen-grain having a thick cell-wall of its own.

18. **Chlorophyll.**—Protoplasm itself is colorless or nearly so, but it may make a staining substance, and stain all or a part of itself. Thus it is very common to find that certain parts of a cell are of a bright green color on account of a green substance—Chlorophyll—which stains those portions

of the protoplasm. As a rule protoplasm does not form chlorophyll in darkness, and even that which is already formed disappears in prolonged darkness.

19. The protoplasm which is stained by chlorophyll is commonly in little rounded masses; in a few cases it is in bands or star-shaped masses. These masses are called chlorophyll-bodies, chlorophyll-grains, or chlorophyll-granules. It must not be forgotten that chlorophyll is the staining substance, while the chlorophyll-grain is the stained protoplasm mass. The two may be separated by alcohol, which dissolves out the chlorophyll, leaving the grain of protoplasm.

Practical Studies.—(*a*) Mount a leaf of a moss and examine for chlorophyll-grains.

(*b*) Soak a few moss-leaves in alcohol for some time and note the decoloration of the chlorophyll-grains. Note the green color given to the alcohol.

(*c*) Mount Green Slime (by scraping off the green coating of rocks, etc.) and note that the whole protoplasm is stained with the chlorophyll.

(*d*) Make sections of a potato-stem grown in darkness. Compare this with a stem of the same plant grown in light.

(*e*) Make sections of blanched celery. Compare with unblanched.

(*f*) Dissolve out the chlorophyll (by alcohol) from a specimen (any of the foregoing) and then treat with iodine. Note the brown color given to the bleached chlorophyll-grains, showing them to be protoplasm.

20. **Starch.**—Many cells of common plants contain little grains of starch (Fig. 5). In some cases, as in the potato tuber, the cells are only partially filled, but in other cases, as in rice, wheat, Indian corn, etc., the starch is packed so closely in the cells as to leave very little unfilled space.

21. The starch of every plant is originally manufactured in a chlorophyll-body, that is, in a mass of stained protoplasm. It moreover forms only in the light, so that plants

which have no chlorophyll, or which grow in darkness, do not make starch.

22. Chemically, starch is much like sugar and cellulose, and like them it is composed of carbon, hydrogen, and oxygen ($C_{12}H_{20}O_{10}$). It contains water in its organization, which may be driven off by heat, or by the application of reagents, when it loses its structure.

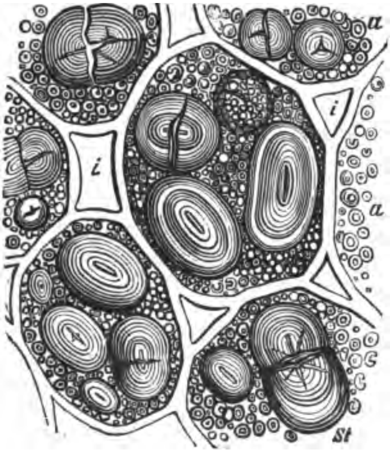


FIG. 5.—A few cells of the seed of a Pea, showing large starch-grains (*St*) and the little granules of aleurone (*a*). At *i*, *i*, are shown intercellular spaces. Magnified 800 times.

23. Starch is a plant-food. It is produced by the green protoplasm for the nourishment of the plant. As it forms only in light, during the day it accumulates, but at night by the continued growth of the plant it is mostly used up. Whenever there is more made than the plant requires, the surplus is stored in certain cells for future use.

Practical Studies.—(*a*) Scrape off a little of the substance of the cut surface of a potato tuber. Mount in water and examine under the microscope, using the ¼ objective. Note the ovate starch-grains, which are concentrically striated. Now add a small drop of iodine and note the blue coloration, which becomes purple or purple-black if much iodine is used.

(*b*) Make an extremely thin slice of the potato-tuber and treat as before, so as to observe starch-grains in the cells. By staining such a section with carmine the protoplasm in the starch-bearing cell may be made evident.

(*c*) Study the starch of wheat, rice, Indian corn, oats, etc.

(*d*) Mount carefully a few threads of Pond Scum (Spirogyra) which has been for some hours in the sunlight. Note the aggregations of minute starch-grains in the spiral chlorophyll-body (Fig. 6). Now add iodine and observe the coloration of starch-grains.

(*e*) Make thin sections of leaves which have been in the light for some hours, and observe minute starch-grains in the chlorophyll-bodies. Use iodine as above

(*f*) Make longitudinal sections of ripened apple-twigs and note the starch stored in certain cells of the pith for use when growth is resumed.

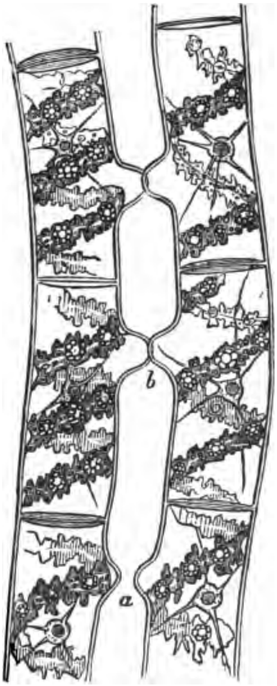


FIG. 6.—Two plants of Pond Scum (Spirogyra), showing spiral chlorophyll-bodies, each with aggregations of starch. At *a* and *b* the cells are beginning to branch preparatory to uniting. Magnified 500 times.

start

24. **Aleurone.**—In mature seeds and tubers there are commonly to be found small rounded granules of albuminous matter to which the name of Aleurone has been given (Fig. 5). It is, in part at least, the protein matter of the older botanists. It is also identical with what has been called the gluten of the grains of wheat, rye, oats, etc.

25. Aleurone is poorly understood, but it appears to be a dry resting state of protoplasm. Some, if not all, of it

may become active again upon the access of water and the proper temperature. Possibly some of it serves as food for protoplasm in the germination of seeds.

Practical Studies.—(*a*) Mount in alcohol a thin slice of a ripe pea. Note the small granules (along with large starch-grains) in the cells (Fig. 5). Apply iodine, which will stain the aleurone yellow or brownish-yellow.

(*b*) Make a similar study of the aleurone of the bean.

(*c*) Make sections of the foregoing and mount in water to observe the solution of the aleurone grains. The process may be hastened by adding a very little potassic hydrate.

(*d*) Make thin cross-sections of a wheat-kernel and study the gluten (aleurone) cells of the inner bran. Add iodine.

(*e*) Make a similar study of the bran of rye, oats, and Indian corn.

26. **Crystals.**—Some cells of certain plants contain crystals (Fig. 7). These are of various shapes, one of the most common forms being needle-shaped, while others are cubical, prismatic, etc. They are frequently clustered into little masses.

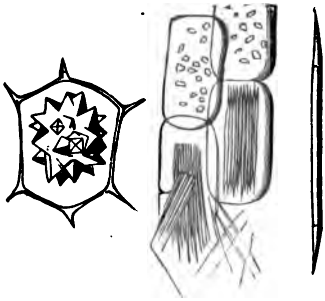


FIG. 7.—Crystals of calcium oxalate. The right-hand portion of the figure shows two cells of the Rhubarb, with their contained crystals, and one enlarged. On the left is a crystal from the beet. Much magnified.

27. Crystals are for the most part composed of calcium oxalate. That is, they are a combination of lime and oxalic acid. A few have a different chemical composition—as the calcium carbonate crystals found in nettles, hops, hemp, etc., besides others of still more infrequent occurrence.

28. Crystals appear to be the residues from chemical reactions which take place in the interior of plants, and they probably have no further use.

Practical Studies.—(*a*) Mount in water several thin longitudinal sections of the stem of the Spiderwort (Tradescantia) and note the bundles of needle-shaped crystals in enlarged, thin-walled cells. Many crystals will be found floating free in the water, having been separated in the preparation of the specimen.

(*b*) Similar sections of the stem of the Evening Primrose, Fuchsia, Balsam or Touch-me-not (Impatiens), and Garden Rhubarb will also show needle-shaped crystals.

(*c*) Other crystal forms may be obtained from the beet, onion (the scales), Pigweed or Lamb's Quarters (Chenopodium), etc.

29. **The Cell-Sap.**—All parts of a living cell are saturated with water. It enters into the structure of the cell-wall; it makes up the greater part of the bulk of the protoplasm, and it fills the vacuoles. It holds in solution the food-materials absorbed from the air and soil, and the surplus soluble substances manufactured by the plant.

30. Among the many substances dissolved in the cell-sap the more important are Sugar and Inulin. Of the former there are two varieties, viz., sucrose, or cane-sugar ($C_{12}H_{22}O_{11}$), and glucose, or grape-sugar ($C_{12}H_{24}O_{12}$), which differ in their sweetness as well as in other properties.

31. Cane-sugar exists in great abundance in the cell-sap of sugar-cane, sugar-maple, sugar-beet, Indian corn, and in greater or less quantity in nearly all higher plants. Grape-sugar is found in many fruits, sometimes mixed with cane-sugar; thus in grapes, cherries, gooseberries, and figs it is the only sugar present, while in apricots, peaches, pine-apples, plums, and strawberries it is mixed with cane-sugar.

32. Inulin ($C_{12}H_{20}O_{10}$) is a soluble substance related to starch and sugar, which is found mainly in the cell-sap of certain Composites, as the sunflower, dahlia, elecampane (Inula), etc.

Practical Studies.—(*a*) Make a thin section of the stem of any herbaceous plant, as a Geranium; examine at once without a cover-glass, noting the wateriness. Lay the specimen aside for half an hour or so, and then note its shrinkage by loss of water.

(*b*) Mount a few plants of Pond Scum (Spirogyra) in a very little water. Examine under the high power of the microscope, and while doing this flow glycerine under the cover-glass. The glycerine imbibing water with great avidity withdraws the water of the cell-sap from the cells, causing them to collapse.

(*c*) The presence of sugar may be demonstrated in many cases by taste alone, as in the stems of cane and Indian corn.

(*d*) Cane-sugar when abundant may be crystallized out (in small stellate crystals) from cell-sap by the use of strong alcohol or glycerine.

(*e*) Make thin slices of the root of the sunflower or dahlia, and soak for some days in alcohol: the inulin will appear in the shape of sphere-crystals of greater or less size, according as the crystallization has been slower or more rapid.

(*f*) The presence of acids in the cell-sap of many plants may be shown by placing a moist cut surface in contact with blue litmus-paper. The latter will be distinctly reddened.

CHAPTER II.

THE TISSUES OF PLANTS.

33. Some plant-cells live alone, and are not connected with any others; some which are at first separate afterward unite into a cell-colony. In most cases, however, the cells are united to each other from the beginning of their existence into what are called **tissues**.

34. As understood in this book a plant-tissue is an assemblage of similar cells which have been united with each other from their beginning. The cells in a tissue may be arranged in rows, surfaces, or masses: in the first the growth has been by the fission of cells in one plane only, in the second from fission in two planes, and in the third from fission in three planes.

35. In the lower plants the cells are all alike, or so nearly so that they constitute but one kind of tissue. As we ascend from these simple forms the cells begin to show differences, some being especially developed for one purpose, and some for another; and these differences become more numerous and more sharply marked as we approach the higher plants. This at last gives us many kinds of tissues, which may be distinguished from each other by characters of greater or less importance. However, they may all be brought within seven general kinds, each kind showing many varieties.

36. **Soft Tissue** (*Parenchyma*).—This is the most abundant tissue in the vegetable kingdom; it is at once the

most important and the most variable. It is composed of cells whose walls are thin, colorless, or nearly so, and transparent; in outline they may be rounded, cubical, polyhedral, prismatic, cylindrical, tabular, stellate, and of many other forms. When the cells are bounded by plane surfaces, generally, but not always, the end planes lie at right angles to the longer axis of the cells.

37. This tissue makes up the whole of the substance of many of the lower plants, while in the higher it composes the essential portions of the assimilative (green), vegetative (growing), and reproductive parts.

38. **Thick-angled Tissue** (*Collenchyma*).—The cells of this tissue are elongated, usually prismatic, and their transverse walls are most frequently horizontal, rarely inclined. The walls are greatly thickened along their longitudinal angles, while the remaining parts are thin (Fig. 8). The cells contain chlorophyll, and retain the power of fission. Wet specimens show by transmitted light a characteristic bluish-white lustre, which is best seen in cross-sections.

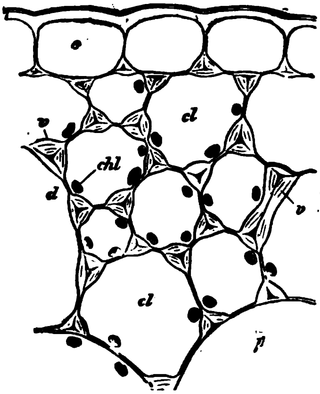


FIG. 8.—Cross-section of thick-angled tissue (*cl*) of Begonia petiole, showing the thickened angles. *e*, epidermis; *chl*, chlorophyll-bodies. Magnified 550 times.

39. Thick-angled tissue is found beneath the epidermis of most flowering plants (and some ferns), usually as a mass of considerable thickness, and is doubtless developed from soft tissue for the purpose of giving support and strength to the epidermis.

40. **Stony Tissue** (*Sclerenchyma*).—In many plants the hard parts are composed of cells whose walls are thickened, often to a very considerable extent (Fig. 9). The cells are usually short, but in some cases they are greatly elongated; they are sometimes regular in outline, but more frequently they are extremely irregular. They do not contain chlorophyll, but in some cases (e.g., in the pith of apple-twigs) they contain starch.

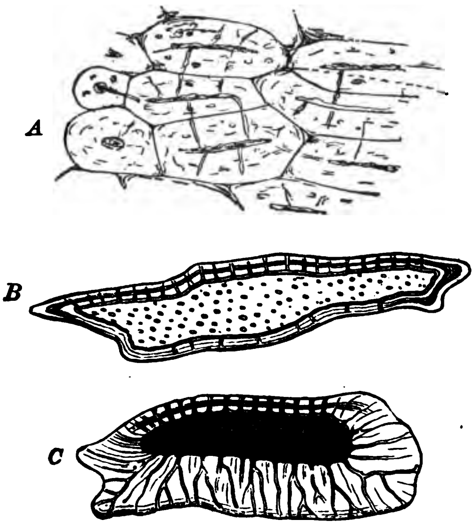


FIG. 9.—Stony tissue. *A*, from shell of Hickory-nut; *B* and *C*, from underground stem of the common Brake (Pteris). Magnified 400 to 500 times.

41. **Fibrous Tissue.**—This is composed of elongated, thick-walled, and generally fusiform fibres (Fig. 10), whose walls are usually marked with simple or sometimes bordered pits. These fibres in cross-section are rarely square or round, but most generally three- to many-sided. They are found in, or in connection with, the woody bundles of ferns

and flowering plants, and give strength and hardness to their stems and leaves.

42. Two varieties of fibrous tissue may be distinguished, viz., (1) Bast (Fig. 10, *B*), and (2) Wood (Fig. 10, *A*).. The fibres of the former are usually thicker walled, more flexible, and of greater length than those of the latter. In both forms the fibres are sometimes observed to be partitioned.

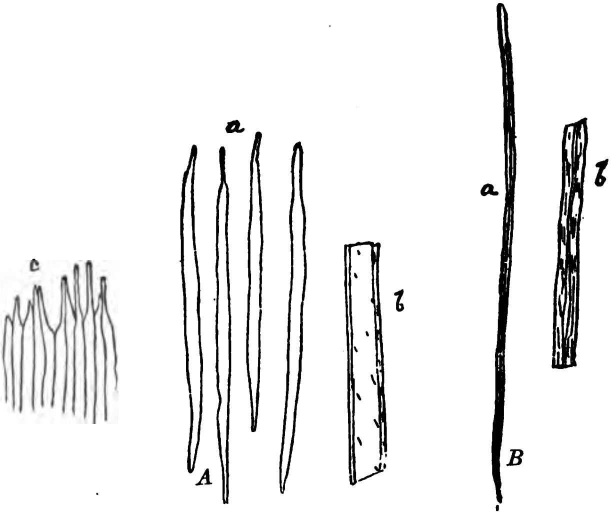
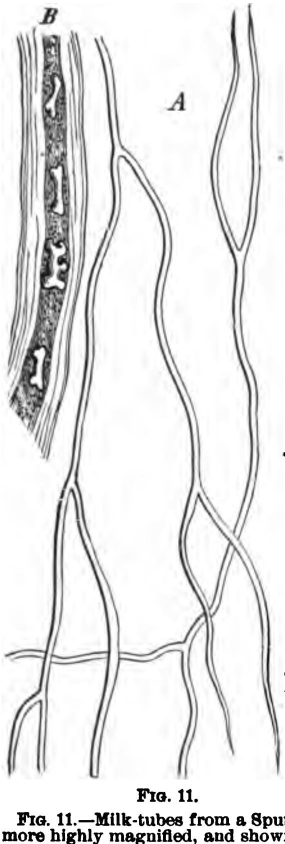


FIG. 10.—*A*, wood-fibres of Silver Maple isolated by Schulze's maceration; *B*, bast-fibres; *b*, *b*, portions of fibres more highly magnified.

43. **Milk Tissue** (*Laticiferous Tissue*).—In many orders of flowering plants tissues are found which contain a milky or colored fluid—the latex. For the sake of simplicity two general forms may be distinguished: (1) that *composed of simple or branching tubes* (Fig. 11), which are scattered through the other tissues. As found in the Spurge family, they are somewhat simply branched and have very thick



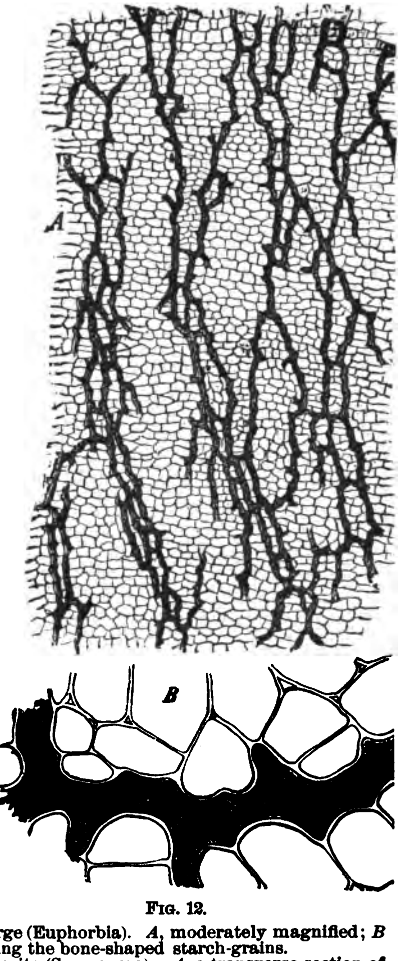


Fig. 11. Fig. 12.

Fig. 11.—Milk-tubes from a Spurge (Euphorbia). *A*, moderately magnified; *B* more highly magnified, and showing the bone-shaped starch-grains.

Fig. 12.—Milk-vessels of a Composite (Scorzonera). *A*, a transverse section of the root; *B*, the same more highly magnified.

walls (Fig. 11, *B*); in other plants they are thin-walled. and are sometimes inclined to anastomose. From their position it is quite certain that the tubes of this form of milk-tissue frequently replace bast-fibres. In other cases, however, they appear not to be of this nature, but to arise from the soft tissue by the absorption of the horizontal partition-walls.

44. (2) The other form is that composed of *reticulately anastomosing vessels.* Here the tissue is the result of the fusion of great numbers of short cells. The walls are thin and often irregular in outline. In chicory, lettuce, etc., this form of milk-tissue is very perfectly developed as a constituent part of the outer portion of the woody bundles (Fig. 12, *A* and *B*).

45. **Sieve Tissue.**—As found in the flowering plants this tissue is for the most part made up of sieve-ducts and the so-called latticed cells. The former (the sieve-ducts) consist of soft, not lignified, colorless tubes of rather wide diameter, having at long intervals horizontal or obliquely placed perforated septa. The lateral walls are also perforated in restricted areas, called sieve-discs, and through these perforations and those in the horizontal walls the protoplasmic contents of the contiguous cells freely unite (Fig. 13).

46. The tissue composed of these ducts is generally loose, and more or less intermingled with soft tissue; in some cases even single ducts run longitudinally through the substance of other tissues. In the form described above it is found only as one of the components of the outer or bark portion of the woody bundles of plants.

47. The so-called *latticed cells* are probably to be regarded as undeveloped sieve-ducts, and hence the tissue they form may be included under sieve-tissue. Latticed cells are thin-walled and elongated; they differ from true

sieve-ducts principally in being of less diameter, and in having the markings but not the perforations of sieve-discs.

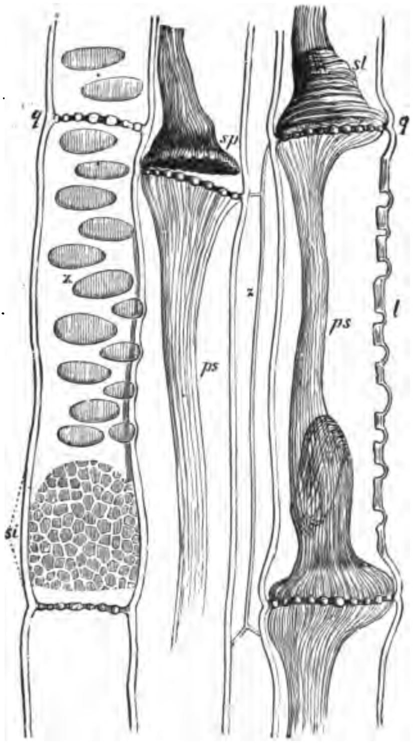


Fig. 13.—Longitudinal section through the sieve-tissue of Pumpkin-stem. *q*, *q*, section of transverse sieve-plates; *si*, lateral sieve-plate; *x*, thin places in wall; *l*, the same seen in section; *ps*, protoplasmic contents contracted by the alcohol in which the specimens were soaked; *sp*, protoplasm lifted off from the sieve-plate by contraction; *sl*, protoplasm still in contact with the sieve-plate. Magnified 550 times.

Both of these differences are such as might be looked for in undeveloped sieve-tissue.

In the corresponding parts of the woody bundles of conifers and ferns a sieve-tissue is found which differs somewhat from that described above. In Conifers the sieve-discs, which are of irregular outline, occur abundantly upon the oblique ends and radial faces of the broad tubes (Fig. 14). In the Horsetails (Equisetum) and Adder-tongues (Ophioglossum) they are prismatic, with numerous horizontal but not vertical sieve-discs; in Brakes (Pteris) and many other ferns they have pointed extremities, and are greatly elongated, bearing the sieve-discs upon their sides. In the larger Club-mosses the sieve-tubes are prismatic and of great length; in the smaller species there are tissue elements destitute of sieve-discs, but which are otherwise, including position in the stem, exactly like the sieve ducts of the larger species.

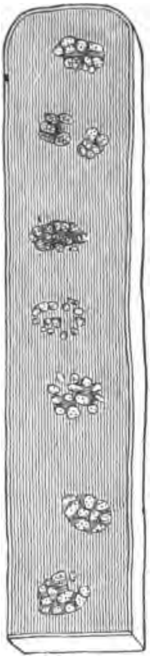


FIG. 14.—Sieve-tube of Big-tree of California (Sequoia gigantea), taken from the bark of an old stem. Magnified 375 times.

48. **Tracheary Tissue.**—Under this head are to be grouped those vessels which, while differing considerably in the details, agree in having thickened walls, which are generally perforated at the places where similar vessels touch each other. The thickening, and as a consequence the perforations, are of various kinds, but generally there is a tendency in the former to the production of spiral bands; this is more or less evident even when the bands form a network. The transverse partitions, which may be horizontal or oblique, are in some cases perforated with small openings, in others they are almost or entirely absorbed. The diameter of the vessels is usually considerably greater than that of the surrounding cells and elements of other tissues, and this alone in many cases may serve to distinguish them. When young they contain protoplasm, but as they become older this disappears, and they then contain air.

Tracheary tissue is found only in ferns and their relatives and the flowering plants. The principal varieties of vessels found in tracheary tissues are the following:

49. (1) *Spiral Vessels,* which are usually long, with fusiform extremities; their walls are thickened in a spiral manner with one or more simple or branched bands or fibres (Fig. 15, *v''*, *v'''*, *v''''*). This form may be regarded as the typical form of the vessels of tracheary tissue. ***Ringed*** and ***reticulated*** vessels are opposite modifications of the spiral form; the first are due to an under-development of the thickening in the young vessels, resulting in the production here and there of isolated rings (Fig. 15, *v*); reticulated vessels are due, on the contrary, to an over-development, which gives rise to a complex branching and anastomosing of the spirals (Fig. 15, *v'''''*).

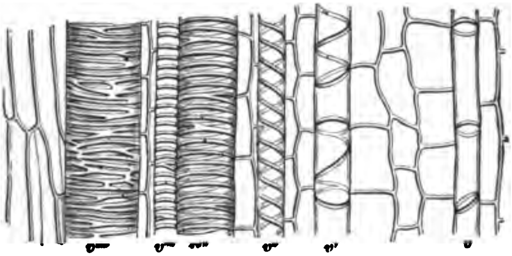


FIG. 15.—Longitudinal section of a portion of the stem of Garden Balsam (Impatiens). *v*, a ringed vessel; *v'*, a vessel with rings and short spirals; *v''*, a vessel with two spirals; *v'''* and *v''''*, vessels with branching spirals; *v'''''*, a vessel with irregular thickenings, forming the reticulated vessel.

50. (2) *Scalariform Vessels.*—These are prismatic vessels whose walls are thickened in such a way as to form transverse ridges. They are wide in transverse diameter, and their extremities are fusiform or truncate (Fig. 16).

51. (3) *Pitted Vessels.*—The walls of these vessels are thickened in such a way as to give rise to pits and dots.

The vessels are usually of wide diameter; in some forms they are crossed at frequent intervals by perforated horizontal or inclined septa (Fig. 17); in other forms they have fusiform extremities.

52. (4) *Tracheïds.*—These consist for the most part of single closed cells; otherwise they possess the characters of vessels. In one form (Fig. 18), as in the so-called wood-cells of Conifers, they are intermediate in structure between the pitted vessels and the fibres of the wood of other flowering plants. Every gradation between these tracheïds and the other forms of tracheary tissue occur. In another form, as in the wood of many common trees and shrubs, the tracheïds are shorter than in the preceding, quite

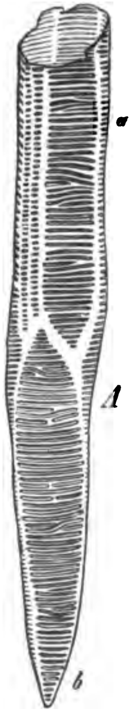


FIG. 16.

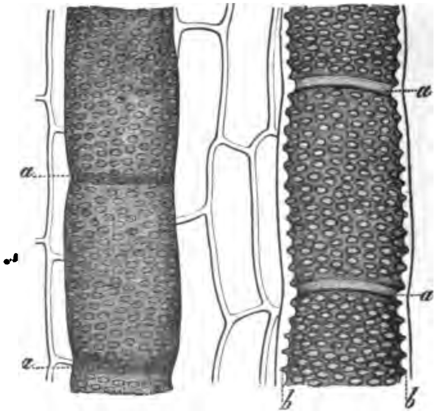


FIG. 17.

FIG. 16.—Scalariform vessels of the common Brake (Pteris).

FIG. 17.—Pitted vessels of Dutchman's Pipe (Aristolochia sipho), from a longitudinal section of the stem; the vessel on the right is seen in section, that on the left from without. *a*, *a*, rings, which are remnants of the original transverse partitions; *b*, *b*, sections of the walls.

regular in their form, and with tapering extremities (Fig. 19). Their walls are but slightly thickened, and are marked with spirals and pits. When the wall between two contiguous cells breaks through or becomes absorbed, the close relation of such tracheïds to spiral vessels is readily seen.

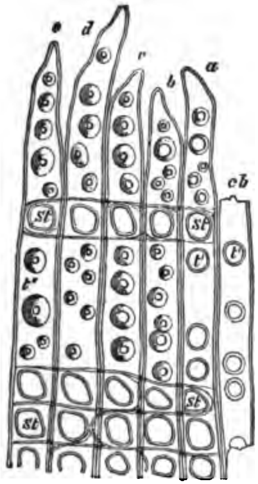


FIG. 18.

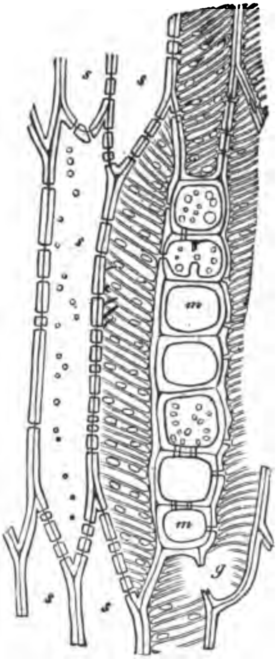


FIG. 19.

FIG. 18.—Ends of several tracheïds from the wood of a Pine, showing bordered pits Magnified 325 times.

FIG. 19.—Tracheïds from the stem of Laburnum. *m, m*, cells of a medullary ray. At *g*, a partition is broken through. Magnified 375 times.

Tracheïds may be regarded as composing a less differentiated form of tissue, related on the one hand to true tracheary tissue and on the other to fibrous tissue.

Practical Studies.—The student should here make a good many observations upon the tissues described above, so as to become thoroughly familiar with at least their typical forms. The following outline may direct him in his first studies:

I. *Soft Tissue.*—(*a*) Make very thin cross and longitudinal sections of a green stem of Indian corn. After excluding the woody bundles, the whole of the central part of the stem is soft tissue.

(*b*) Make similar sections of the central part of the stem of the cultivated geranium.

(*c*) Make a very thin cross-section of an apple-leaf: the green cells are of soft tissue.

(*d*) Mount a whole moss-leaf: it is entirely composed of soft tissue, although in its rudimentary midrib the cells have elongated, as if foreshadowing the higher tissues.

(*e*) Mount several threads of Pond Scum: the whole plant is here composed of soft tissue.

II. *Thick-angled Tissue.*—(*a*) Examine a leaf-stalk of the squash or pumpkin, and note the whitish bands, one or two millimetres wide, which extend from end to end just beneath the epidermis. These are bands of thick-angled tissue. They may be readily torn out, when the stalk will be found to have lost much of its strength.

(*b*) Make a very thin cross section of the preceding leaf-stalk, and note the appearance of the thick angled tissue first under a low power and then under a higher. The sections must be made exactly at right angles to the axis of the bands of tissue in order to show well.

(*c*) Make a number of longitudinal sections of the same leaf-stalk, in each case cutting through a band of the thick-angled tissue. Some of these will show the thickened angles, although there is always some difficulty in making them out in this section.

(*d*) The stems of squash, pumpkin, Pigweed or Lamb's Quarters (Chenopodium), beet, and many other plants may be taken up next, and their thick-angled tissue studied in cross and longitudinal sections.

III. *Stony Tissue.*—(*a*) Break the shell of a hickory-nut, and after smoothing the broken surface cut off a very small thin slice; mount in water and a little potassic hydrate: the cell walls are so greatly thickened as to almost obliterate the cell-cavity.

(*b*) Study similarly the stony tissue of the cocoa-nut, walnut, peach, cherry, etc.

(*c*) Make cross-sections of the seed-coat of the apple, squash, melon wild cucumber (Echinocystis), etc. It is instructive to make sections also, parallel to the surface of the seeds.

(*d*) Make longitudinal sections of the pith of apple-twigs and note that some of the cells have thickened walls. These are very hard, and are to be regarded as a form of stony tissue. They contain starch.

IV. *Fibrous Tissue.*—(*a*) Split a young maple-twig, then with the scalpel start a thin longitudinal radial section, completing it by tearing it off. Mount in water. The torn end will show good wood-fibres.

(*b*) Make a very thin cross-section of the wood of the same twig, using a very sharp scalpel. Note the angular shape of the wood-fibres in this section.

(*c*) Make a cross-section of the bark of the same twig and note the white bundles of bast-fibres, each fibre having greatly thickened walls and a very narrow cell-cavity.

(*d*) Now make several longitudinal sections of the same twig so as to cut through one of the bundles of bast-fibres. Note the great length of the bast-fibres.

(*e*) Make cross-sections of the wood of various trees, as oak, hickory, elm, ash, poplar, willow, and basswood, and note the differences in the amount and compactness of their fibrous tissue.

(*f*) To isolate the wood-fibres, make a number of sections as in (*a*) above, then heat for a minute or less in nitric acid and potassium chlorate. The fibres may now be separated under a dissecting microscope, or the specimens may be transferred to a glass slide and dissected by tapping gently upon the centre of the cover-glass. This is known as Schulze's maceration.

V. *Milk-Tissue.*—In studying milk-tissue it is necessary first to examine a drop of the milk (latex) under the microscope by transmitted light. When so examined it presents quite a different appearance from that by ordinary reflected light: thus white latex appears to be light granular brown.

(*a*) Make thin longitudinal sections of the stem of a Milkweed (Asclepias). By careful searching, tubes containing latex (appearing light granular brown) may be seen.

(*b*) Make a similar study of the stem of the large Spurge (Euphorbia) of the greenhouses. Its milk-tissue is thick-walled and easily made out.

(*c*) The more complex or reticulated forms of milk-tissue may be obtained from the stems of wild lettuce, garden-lettuce, poppy, and blood-root.

(*d*) Collect a quantity of latex of a Spurge or Milkweed in a watch-glass and slowly evaporate it: the residue will be found to consist of a sticky, elastic material resembling india-rubber.

VI. *Sieve-Tissue.*—As sieve-tissue is always found in the woody bundles which run lengthwise through the higher plants, it is necessary first to make a cross-section of the stem to be studied in order to determine exactly the position of such bundles. It must be borne in mind that in most cases the sieve-tissue is confined to the outer side of the bundle, that is, to the side which faces the circumference of the stem. In the pumpkin, squash, melon, and related plants the bundles contain sieve-tissue on both outer and inner sides, that is on the side which faces the axis of the stem as well as on that which faces the circumference. This double nature of the bundles of these plants must be remembered in studying their sieve-tissue.

(*a*) Make a longitudinal radial section through one of the larger bundles of the stem of the pumpkin. The sieve-tissue will be distinguished by the thick-looking cross-partitions (this is mainly due to the adhesion of the protoplasm to the walls). By adding alcohol or glycerine the protoplasm of each cell may be contracted as in Fig. 13. In some cases where the partitions are oblique the perforations may be seen.

(*b*) Make very thin cross-sections of pumpkin-stem and examine carefully for sieve-plates. Where the section is made close to a plate it may be easily seen in such a specimen.

(*c*) Make similar studies of the stem of the Indian corn.

VII. *Tracheary Tissue.*—Here, as in the preceding, it is necessary, especially in herbaceous plants, to first determine by a cross-section the position of the woody bundles, as tracheary tissue is always confined to them.

(*a*) Make a thin longitudinal radial section through a bundle of the stem of the Garden Balsam or Touch-me-not (Impatiens). If successfully made it will show successively, passing *outward*, ringed, spiral, reticulated, and sometimes scalariform and pitted vessels, with gradations from one to the other, as in Fig. 15.

(*b*) Make a thin cross-section of the same and study carefully in connection with the foregoing.

(*c*) Make similar sections of the bundles of Indian corn. The large vessels which can be seen with the naked eye in cross section are pitted.

(*d*) Study in like manner the tracheary tissue in the bundles of the pumpkin-stem. Here the large pitted vessels (which are very distinctly visible to the naked eye) have their walls thrown into numerous folds.

NOTE.—The large pores which are so distinctly visible in oak, chestnut, hickory, walnut, ash, and many other kinds of woods are pitted vessels like those of the Indian corn and pumpkin.

(*e*) Excellent scalariform vessels may be obtained from the bundles of the leaf stalks of ferns, or better still from the underground stem.

In the latter the bundles lie adjacent to the thick dark bands of fibrous tissue.

(*f*) The trachelds of Conifers (pines, spruces, etc.) make up very nearly the whole bulk of the wood of these trees. Make a longitudinal radial section of a pine-twig by the method employed in studying fibrous tissue (IV. *a*, above). Note that the trachelds bear some resemblance to the wood-fibres of other wood. However, their large round bordered pits are characteristic.

(*g*) Make longitudinal tangential sections of the same twig. Note that the bordered pits are not seen (except in section) in specimens so made.

(*h*) Make cross-sections of the same twig and note that the tissue is homogeneous. Compare with a similar section of an oak-twig, and note the absence in the pine of the large pitted vessels which are so well shown in the oak.

(*i*) Make very thin longitudinal radial sections of the wood of hackberry. By careful examination trachelds may be found resembling the wood-fibres, but marked with fine spirals.

(*j*) Similar trachelds may be found intermingled with the wood-fibres of other trees, as the maple, box-elder, elm, etc.

53. **The Primary Meristem.** — Under this name are grouped the unformed and growing tissues found at the ends of young stems, leaves, and roots. In these parts the tissues described above (paragraphs 36 to 52) have not yet formed; they are, on the contrary, composed entirely of a mass of thin-walled, growing, and dividing cells containing an abundance of protoplasm. In the lower plants the meristem-cells do not change much in their configuration or general structure as they develop into the ordinary plant-cells; but the higher the type of plant, the greater are the changes which take place during the development of meristem into permanent tissues.

54. In most plants aside from the flowering plants the primary meristem is the result of the continually repeated division of a single mother-cell situated at the apex of the growing organ. In the simplest forms this apical cell

is the terminal one of a row of cells, as in many seaweeds and fungi. The apical cell, in such cases, keeps on growing in length, and at the same time horizontal partitions are forming in its basal portion. In this way long lines of cells may originate.

55. In the more complicated cases the segments cut off from the apical cell grow and subdivide in different planes, so as to give rise to masses of cells. The partitions which successively divide the apical cell are sometimes perpendicular to its axis, but more frequently they are oblique to it. In most mosses, for example (Fig. 20), the apical cell is a triangular, convex-based pyramid, whose apex is its proximal portion. The successive segments are cut off from the apical cell by alternate partitions parallel to its sides, thus giving rise to three longitudinal rows of cells. Most ferns and their relatives have an apical cell not much different

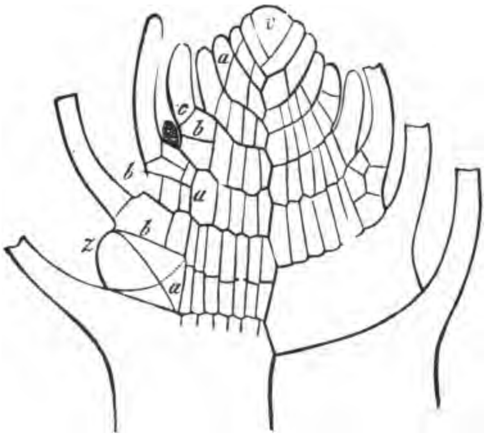


Fig. 20.—Longitudinal section of apex of stem of a Moss (Fontinalis antipyretica). *v*, apical cell; *z*, apical cell of lateral leaf-forming shoot, arising below a leaf; *c*, first cell of leaf; *b*, *b*, *b*, cells forming cortex.

from that of the majority of mosses. In Horsetails, for example, it is an inverted triangular pyramid, having a convex base. The segments (daughter-cells) are cut off by alternating partitions parallel to the plane sides of the pyramid, as in the mosses. In some mosses and ferns, however, the apical cell is wedge-shaped—i.e., with only two surfaces—and in such cases two instead of three rows of meristem-cells are formed.

56. In the flowering plants the primary meristem is developed from a group of cells, instead of from a single one; they therefore have no apical cell. This group of cells occupies approximately the same position in the organs of flowering plants as the apical cell does in the mosses and ferns; it is composed of cells which have the power of indefinite division and subdivision.

57. The apical cell and its actively growing daughter-cells in its immediate vicinity, or, in the case of the flowering plants, the apical group of cells with their daughter-cells, constitute the Growing Point or Vegetative Point (*punctum vegetationis*) of the organ. When this active portion is conical in shape it is also called the Vegetative Cone.

CHAPTER III.

THE GROUPS OF TISSUES, OR TISSUE-SYSTEMS.

58. **The Differentiation of Tissues into Systems.**—It rarely happens that the tissues which compose the body of a plant are uniform. In the great majority of cases the cells of the primary meristem become differently modified, so as to give rise to several kinds of tissues. The outer cells of the plant become more or less modified into a boundary tissue, and the degree of modification has relation to its environment. Certain inner cells, or lines of cells, become modified into stony tissue, or some other supporting tissue (thick-angled, or fibrous tissue), and here again there is a manifest relation to the environment of the plant.

59. Certain other inner cells, or rows of cells, become modified into tubes affording a ready means for conduction, and appear to have a relation to the physical dissociation of the organs of the higher plants, in which only they occur. Thus, in physiological terms, there may be a boundary tissue, a supporting tissue, and a conducting tissue lying in the mass of less differentiated ground-tissue.

60. In different groups of plants the elementary tissues described in previous pages are aggregated in different ways, and are variously modified to form these bounding, supporting, and conducting parts of the plant. Several tissues, or varieties of tissue, are regularly united or aggregated in particular ways in each plant, constituting what

may be called Groups or Systems of Tissues. A Tissue-system may then be described as an aggregation of elementary tissues, forming a definite portion of the internal structure of the plant.

61. From what has already been said, it is clear that systems of tissues do not exist in the lowest plants, and that they reach their fullest development only in the highest orders. It is evident also that these systems have no existence in the youngest parts of plants, but that they result from a subsequent development.

62. Many systems of tissues might be enumerated and described; but here again, as with the elementary tissues, while there are many variations, there are also many gradations, having on the one hand a tendency to give us a long list of special forms, and on the other to reduce them to one, or at most to two or three.

63. The three systems proposed by Sachs are instructive, and will be followed here; they are: (1) the Epidermal System, composed mainly of the boundary cells and their appendages (hairs, scales, breathing-pores, etc.); (2) the Fundamental System, which includes the mass of unmodified or slightly modified tissues found in greater or less abundance in all plants (excepting the lowest); (3) the Fibro-vascular System, comprising those varying aggregations of tissues which make up the string-like masses or woody bundles found in the organs of the higher plants.

64. **The Epidermal System of Tissues.**—This is the simplest tissue-system, as it is the earliest to make its appearance, in passing from the lower forms to the higher. It is also (in general) the first to appear in the individual development of the plant. It is sometimes scarcely to be separated from the underlying mass, as in most lower plants;

but in most higher plants it frequently attains some degree of complexity, and is sharply separated from the underlying ground-tissues.

65. In the simpler epidermal structures of the lower plants the cells are generally darker colored, smaller, and more closely approximated than they are in the subjacent mass; in some of the higher fungi a boundary tissue may be easily separated as a thickish sheet, but probably in such case a portion of the underlying mass is also removed. In many lower plants there is absolutely no differentiation of an epidermal portion.

66. The epidermal systems of ferns and flowering plants consist usually of three portions: (1) a layer of more or less modified parenchyma—the epidermis proper—bearing two other kinds of structures which develop from it, viz., (2) hairs, and (3) breathing-pores.

67. **Epidermis.**—The differentiation of parenchyma in the formation of epidermis, when carried to its utmost extent, involves three modifications of the cells, viz., change of form, thickening of the walls, and disappearance of the protoplasmic contents.

68. These may occur in varying degrees of intensity; they may all be slight, as in many aquatic plants and in the young roots of ordinary plants; or the cells may change their form, while there may be little thickening of their walls, as in other aquatic plants and some land-plants which live in damp and shady places; or, on the other hand, the change of form of the cells may be but little, while their walls may have greatly thickened, resulting in a disappearance of their protoplasm, as may be seen in parts of some land-plants which grow slowly and uniformly. When the differentiation of epidermis is considerable, it can usu-

ally be readily removed as a thin transparent sheet of colorless cells.

69. The change in the form of the epidermal cells is due to the mode of growth of the organ of which they form a part; the lateral and longitudinal growth of an organ causes a corresponding extension and consequent flattening of the cells; if the growth has been mainly in one direction, as in the leaves of grasses, or if the growth in two directions has been regular and uniform, the cells are quite regular in outline; where, however, the growth is not uniform the cells become irregular, often extremely so (Fig. 24, page 38).

70. The thickening of the walls is greatest in those plants and parts of plants which are most exposed to the drying effects of the atmosphere. It consists of a thickening of the outer walls, and frequently of the lateral ones also.

71. The outer portion of the thickened walls sometimes separates as a continuous pellicle, the so-called cuticle, which extends uninterruptedly over the cells, and may be readily distinguished from the other portions of the outer epidermal walls. It is insoluble in concentrated sulphuric acid, but may be dissolved in boiling caustic potash. Treated with iodine it turns a yellow or yellowish-brown color. A waxy or resinous matter is frequently developed upon the surface of the cuticle, constituting what is called the *bloom* of some leaves and fruits.

72. The protoplasm of the epidermal cells generally disappears in those cases where there is much thickening of the walls; it is always present in young plants and parts of plants; it is also frequently present in older portions, which are not so much exposed to the drying action of the atmosphere, as in roots, and the leaves and shoots of aquatic plants and of those growing in humid places. In few

cases, however, are granular protoplasmic bodies (e.g., chlorophyll) present in epidermal cells.

73. While the epidermis always consists at first of but one layer of cells, it may become split into two or more layers by subsequent divisions parallel to its surface, as in the Oleander and Cactus.

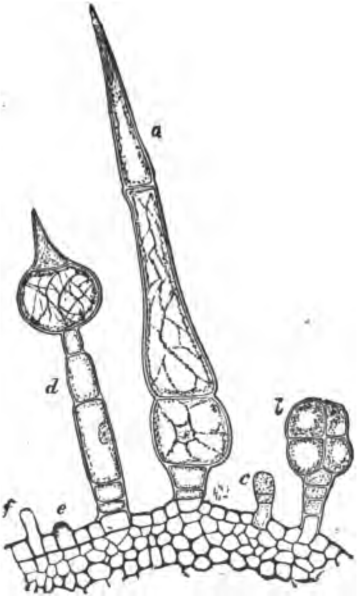


FIG. 21.

FIG. 22.

FIG. 21.—Transverse section of epidermis and underlying tissue of ovary of a squash. *a*, hair of a row of cells; *b* and *d*, glandular hairs of different ages; *e*, *f*, *c*, hairs in the youngest stages of their development. Magnified 100 times.

FIG. 22.—A seedling mustard-plant with its single root clothed with root-hairs; the newest (lowermost) portion of the root is not yet provided with root-hairs.

74. **The Hairs** of the epidermis originate mostly from the growth of single epidermal cells, and on their first appearance consist of slightly enlarged and protruding cells (Fig. 21, *e*, *f*, *c*). These may elongate and form single-celled

hairs, which may be simple or variously branched. The most important of these hairs are those which clothe so abundantly the young roots of most of the higher plants, and to which the name of Root-hairs has been applied (Fig. 22). These are composed of single cells, which have very thin and delicate walls, and are the active agents in the absorption of nutritive matters for the plant. Sometimes the terminal cell of a hair becomes changed into a secreting cell and manufactures a gummy or resinous substance. Such hairs are called Glandular Hairs and are common on many plants (Fig. 23).

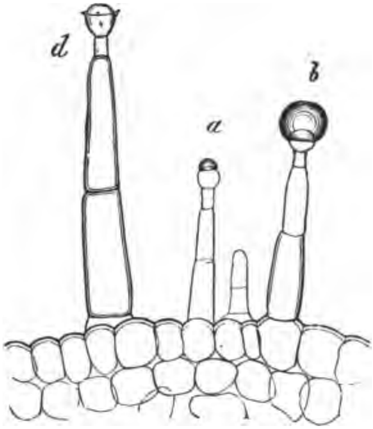


FIG. 23.—Glandular hairs of Chinese Primrose in several stages of development. Magnified 142 times.

75. **Breathing-Pores** (*stomata;* singular, *stoma*) consist, in most cases, of two specially modified chlorophyll-bearing cells, called the guard-cells, which have between them a cleft or slit passing through the epidermis (Fig. 24). These openings are always placed directly over interior intercellular spaces,

76. They occur on aerial leaves and stems most abundantly, being sometimes exceedingly numerous, and are exceptionally found elsewhere, as on the parts of the flowers. On submerged or underground stems and leaves they are found in less numbers, and from true roots they are always absent. The breathing-pores on leaves are generally confined to the lower surface, and when present on the upper they are usually much fewer in number; there are, however, some exceptions to this.

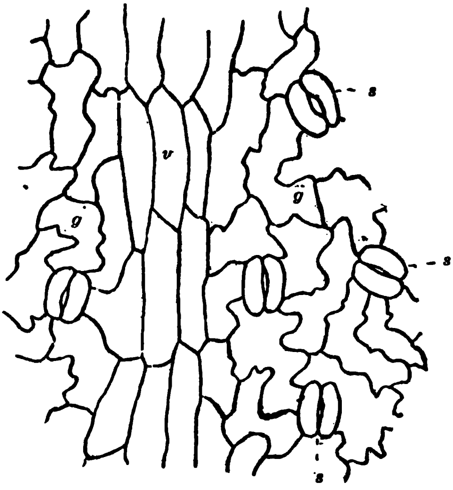


FIG. 24.—A bit of the epidermis of Wild Cucumber (Echinocystis), showing breathing-pores at *s*, *s*, *s*. At *g*, *g*, the epidermal cells are irregular; at *v*, over a vein, they are more regular. Magnified 250 times.

77. In the light, under certain conditions of moisture and temperature, the guard-cells become curved away from each other in their central portions, thus opening the slit and allowing free communication between the external air and that in the intercellular spaces and passages of the leaf.

The number of breathing-pores has been determined for many leaves. The following table will give an idea of their abundance on some common leaves:

	In one square millimetre.		In one square inch.	
	Upper side.	Under side.	Upper side.	Under side.
Olive (Olea europea)	0	625	0	403,125
Black Walnut (Juglans nigra)	0	461	0	298,345
Red Clover (Trifolium pratense)	207	335	133,515	216,075
Lilac (Syringa vulgaris)	0	330	0	212,850
Sunflower (Helianthus annuus)	175	325	112,875	209,625
Cabbage (Brassica oleracea)	138	302	88,910	194,790
Sycamore (Platanus occidentalis)	0	278	0	179,310
Lombardy Poplar (Populus dilatata)	55	270	35,475	174,150
Hop (Humulus lupulus)	0	256	0	165,120
Plum (Prunus domestica)	0	253	0	163,185
Apple (Pirus malus)	0	246	0	158,670
Barberry (Berberis vulgaris)	0	229	0	147,705
Pea (Pisum sativum)	101	216	65,145	139,320
Box (Buxus sempervirens)	0	208	0	134,160
Cherry (Prunus mahaleb)	0	204	0	131,580
Thorn-apple (Datura stramonium)	114	189	73,530	121,905
Indian Corn (Zea mais)	94	158	60,630	101,910
Cottonwood (Populus monilifera)	89	131	57,405	84,495
Wind-flower (Anemone nemorosa)	0	67	0	43,215
Lily (Lilium bulbiferum)	0	62	0	39,990
Iris (Iris germanica)	65	58	41,925	38,410
Oats (Avena sativa)	48	27	30,960	17,415

Practical Studies.—(*a*) Strip off a bit of the epidermis of a Live-for-ever leaf. Mount it in alcohol to avoid air-bubbles, and afterwards add water and a little potassic hydrate. Epidermal cells and breathing-pores may be well seen.

(*b*) Prepare in like manner the epidermis of both upper and under surfaces of a cabbage-leaf. Note the breathing-pores on both surfaces; note also the bloom.

(*c*) Make very thin cross-sections of a cabbage-leaf (by placing a piece of leaf between two pieces of elder-pith) so as to secure cross-sections of the epidermis. Note the thickened outer wall of the epidermal cells. In some cases the separable cuticle may be seen. Now and then a breathing-pore may be seen in cross-section.

(*d*) Make similar sections of the leaf of the oleander, cactus, compass-plant, holly, or any others of a hard texture. Note in some cases (oleander and cactus) that there are several layers of epidermal cells.

(*e*) Mount in alcohol a few hairs of tickle-grass (Panicum capillare) as examples of simple one-celled hairs.

(*f*) Mount in like manner hairs of petunia, verbena, or walnut as examples of hairs made of a row of cells. Note that many of these are glandular.

(*g*) Mount in like manner hairs of the mullein as examples of greatly branched hairs.

78. **The Fibro-vascular System.**—In most of the higher plants portions of the interior tissues early become greatly differentiated into firm elongated bundles, which run through the other tissues. They are composed for the most part of tracheary, sieve, and fibrous tissues, together with a varying amount of parenchyma, and have a general similarity of arrangement and aggregation. In a few cases milk-tissue is associated with those above mentioned. To these collections of tissues the name of Fibro-vascular Bundles has been given. They are also called Woody Bundles and Vascular Bundles, but the name first given is to be preferred.

79. In many plants the fibro-vascular bundles admit of easy separation from the surrounding tissues; thus in the Plantain (Plantago major) they may readily be pulled out upon breaking the leaf-stalk. In the leaves of plants, where they constitute the framework, they are, by maceration, readily separated from the other tissues as a delicate network. In the stems of Indian corn the bundles run through the internodes as separate threads of a considerable thickness.

80. In the fibro-vascular bundle of the stem of Indian

corn the central portion is composed of tracheary tissue, consisting of pitted, spiral, ringed, and reticulated vessels

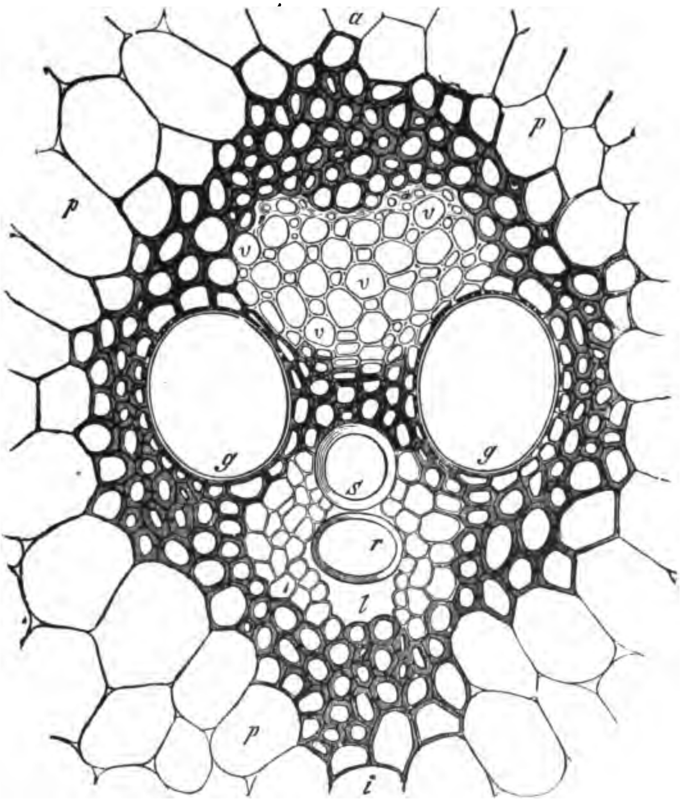


FIG. 25.—Transverse section of fibro-vascular bundle of Indian corn. *a*, side of bundle looking toward the circumference of the stem; *i*, side of bundle looking toward the centre of the stem; *g*, *g*, large pitted vessels; *s*, spiral vessel; *r*, ring of an annular vessel; *l*, air-cavity formed by the breaking apart of the surrounding cells; *v*, *v*, latticed cells, or soft bast, a form of sieve-tissue. Magnified 550 times.

(Fig. 25, *g*, *g*, *s*, *r*, and the tissue between *v*—*s*, *g*—*g*). Lying by the side of the tracheary tissue (on its outer side

as it is placed in the stem) is a mass of sieve-tissue, composed of latticed cells (*v*, *v*, Fig. 25). Surrounding the whole is a thick mass of fibrous tissue composed of elongated, thick-walled cells (the shaded ones in the figure).

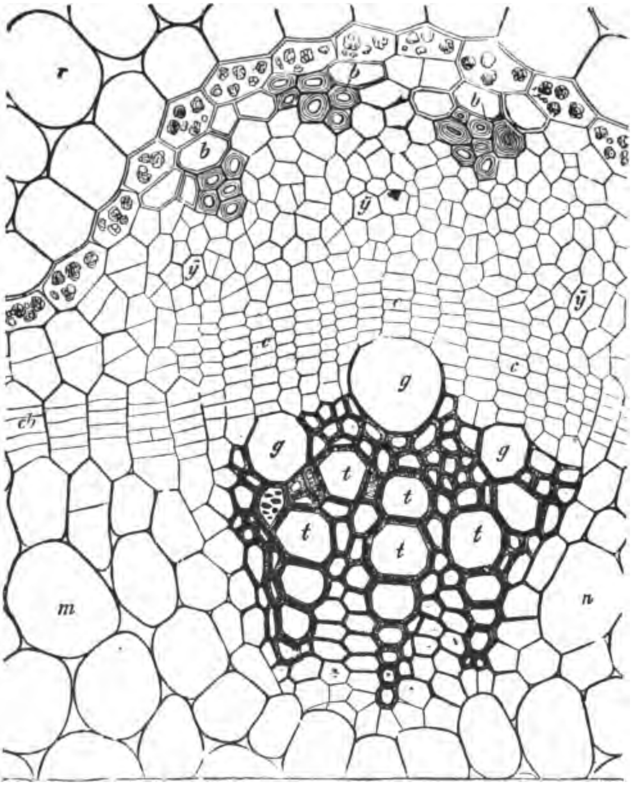


FIG. 26.—Fibro-vascular bundle of Castor-oil Plant. *t*, *t*, *g*, *g*, tracheary tissue; *y*, *y*, sieve-tissue poorly developed; *b*, *b*, bast-fibres; *c*, *c*, cambium-cells. Highly magnified.

81. In the Castor-oil Plant the limits of the fibro-vascular bundles are so poorly marked that in places it is impossible

to tell whether the tissues belong to them or to the surrounding ground-tissues. The inner portion of the bundle (*g*, *g*, *t*, *t*, Fig. 26, and *s* to *t*, Fig. 27) is made up of tracheary tissue of several varieties; on the inner edge of this tracheary portion lie several spiral vessels (*s*, *s*, Fig. 27); next to these, on their outer side, are scalariform and pitted vessels (*t*, *t*, *g*, *g*, Fig. 26; *l*, *t*, *t′*, Fig. 27), intermingled with elongated cells, whose walls are pitted (*h*, *h′*, *h″*, *h‴*, Fig. 27). The last-named are clearly related to the vessels which surround them, and from which they differ only in their less diameter, and in having imperforate horizontal or oblique partitions. They are doubtless properly classed with the tracheïds (see paragraph 52).

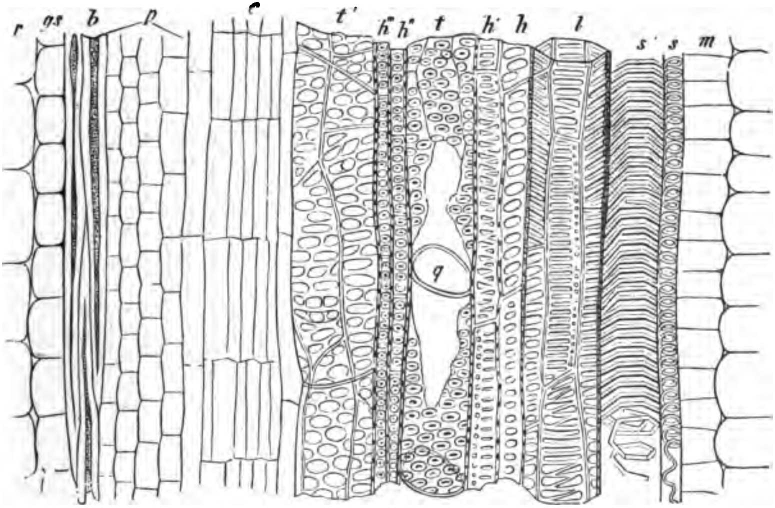


FIG. 27.—A longitudinal radial section of the bundle in Fig. 26.

82. On the outer side of the tracheary portion just described lies a mass of narrow, somewhat elongated, thin-

walled cells, which constitute a true meristem-tissue, to which the name of Cambium* has been given (*c*, *c*, Figs. 26 and 27). Next to the cambium lie, in order, sieve-tissue and soft tissue (parenchyma); these do not occupy separate zones, but are more or less intermingled, forming a mass called the Soft Bast (*y*, *y*, *y*, Fig. 26, and *p*, Fig. 27). The sieve-tissue includes sieve-tubes and cambiform or latticed cells. In the extreme outer border of the bundle is a mass of fibrous tissue (*b*, *b*). The layer of starch-bearing cells

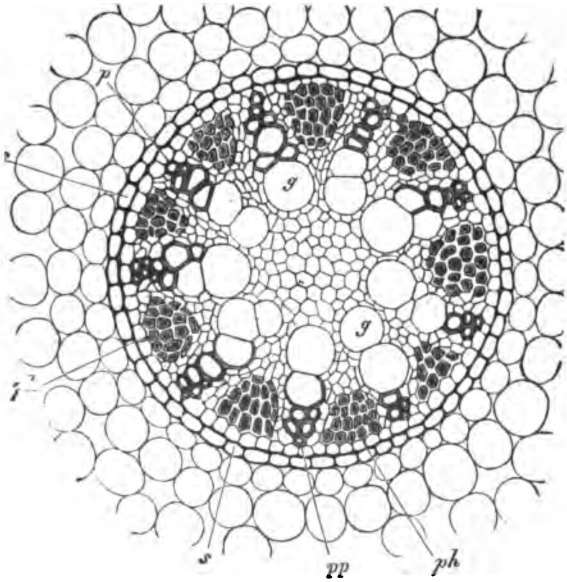


FIG. 28.—Fibro-vascular bundle of root of Sweet Flag (Acorus). *pp*, plates of tracheary tissue; *g*, *g*, pitted vessels; *ph*, sieve-tissue; *s*, bundle-sheath.

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* Cambium, a low Latin word meaning a liquid which becomes glutinous. The term was introduced when the real structure of the part to which it was applied was not understood.

just outside of the last-named tissue is the so-called "bundle-sheath."

83. In most higher flowering plants the fibro-vascular bundles of the stems have a structure essentially like that of the Castor-oil Plant just described. In them it is evident at a glance that the bundle is divided into two somewhat similar portions, an inner and an outer, by the cambium zone. Nägeli, who first pointed out these divisions, named the inner one the Xylem portion, because from it the wood of the stem is formed; the outer he named the Phloëm portion, for the reason that it develops into bark. If we wish to be less technical we may call the first the Wood portion, and the second the Bark portion.

84. In some cases the xylem and phloëm are composed of corresponding tissues, (1) Vessels, (2) Fibres, and (3) Soft Cells. The vessels are the tracheary tissue in the xylem and the sieve-tissue in the phloëm. The fibrous tissue of the xylem is the variety with the shorter and harder fibres, known as wood-fibres; that of the phloëm is composed of the longer and tougher bast-fibres. The soft tissue (parenchyma) of the two portions is much alike.

85. In the fibro-vascular bundle of the young roots of Sweet Flag there are many radially placed plates of tracheary tissue (*pp*, Fig. 28), which alternate with thick masses of sieve-tissue (*ph*). Between these alternating tissues, and within the circle formed by them, there is a mass of soft tissue. The whole bundle is separated from the large-celled soft tissue of the root by a well-marked bundle-sheath (*s*); the latter is bounded interiorly by a layer of active thin-walled cells (the pericambium), from which new roots originate. In the older roots the central cell-mass is transformed into stony tissue.

86. The bundle of the larger Club-mosses (Lycopodium) contains several parallel plates of tracheary tissue. Between the tracheary plates there is in each case a row of sieve-tubes imbedded in a lignified tissue composed of elongated cells (stony, or fibrous tissue?). Around this central fibro-vascular portion there is a layer of soft tissue (parenchyma), and outside of this a bundle-sheath, exterior to which lies a thick mass of fibrous tissue completely enveloping all the previously described tissues.

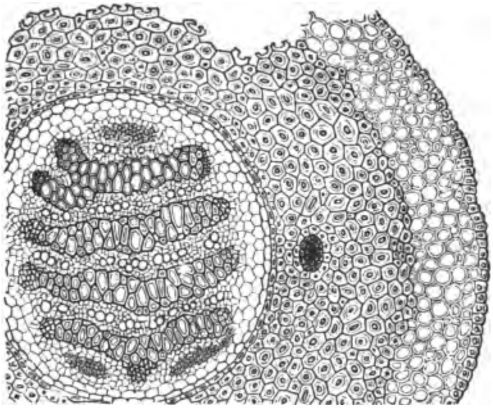


FIG. 29.—Magnified cross-section of the stem of a larger Club-moss (Lycopodium complanatum), showing a fibro-vascular bundle.

87. The bundle in the smaller Club-mosses (Selaginella) is much like a single plate of the preceding. There is in each bundle a central plate of tracheary tissue, consisting of a few narrow spiral vessels in its two edges and a remaining mass of scalariform vessels (Fig. 30). The tracheary portion is surrounded by a tissue of elongated, thin-walled tissue which is, at least in part, a sieve-tissue. In

this and allied species the bundles are curiously isolated from the surrounding ground-tissues of the stem.

88. The fibro-vascular bundle of the underground stem of the common Brake-fern (Pteris) is composed of tracheary, sieve, and soft tissues and a small amount of poorly developed fibrous tissue. In transverse section the bundle has usually an elliptical outline. The great mass of the bundle is made up of large scalariform vessels, which occupy its interior (*g*, *g*, *g*, Fig. 31). Enclosed in the sca-

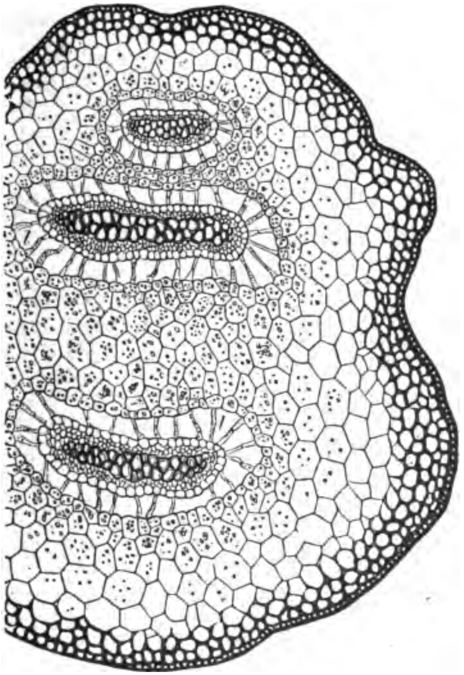


FIG. 30.—Magnified cross-section of the stem of a smaller Club-moss (Selaginella inæquifolia), showing three bundles.

lariform tissue are masses of soft tissue (parenchyma) and a few spiral vessels, the latter occurring near the foci of the elliptical cross-section of the bundle (*s*). Surrounding or partly surrounding the tracheary portion of the bundle is a layer of sieve-tubes (*sp*), separated from the large scalariform vessels by a layer of parenchyma. Outside of the sieve-tissue is a mass of fibrous tissue (*b*), which is itself bounded externally by another layer of parenchyma. The whole bundle is surrounded by a bundle-sheath.

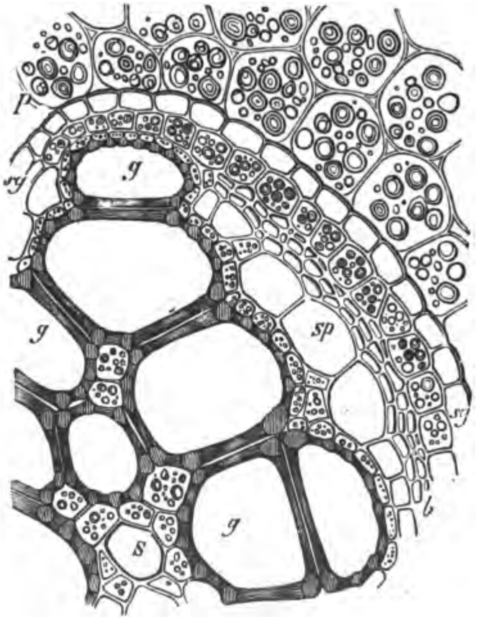


FIG. 31.—Part of a transverse section of the fibro-vascular bundle of the underground stem of the common Brake-fern (Pteris aquilina). *s*, spiral vessel; *g*, *g*, scalariform vessels; *sp*, sieve-tissue; *b*, fibrous tissue; *sg*, bundle-sheath.

89. A noticeable feature in the structure of this bundle

is that the tissues have a concentric arrangement: the tracheary tissue is encircled by a layer of parenchyma; this by one of sieve-tissue; this again by fibrous tissue; and so on.

90. De Bary's classification of fibro-vascular bundles is useful in designating their general plan. He includes all forms under three kinds, viz., (1) the Collateral bundle, which has one mass of xylem by the side of a single mass of phloëm; (2) the Concentric bundle, which has its tissues arranged concentrically around one another; (3) the Radial bundle, which has its tissues arranged radially about its axis.

91. The development of the fibro-vascular bundle takes place in this wise: in the previously uniform primary meristem there arises an elongated mass of cells, constituting the Procambium of the bundle; as it grows older the cells, which were at first alike, become changed into the vessels, fibres, and other elements of the bundle-tissues. In most higher flowering plants this change begins on the two sides of the bundle—i.e., on the outer edge of the phloëm and the inner edge of the xylem; from these points the change into permanent tissue advances from both sides toward the centre of the bundle.

92. In some cases all of the procambium is changed into permanent tissue, forming what is termed the *closed* bundle; in other cases there is left between the phloëm and xylem a narrow zone of the procambium (now called the cambium), forming what is known as the *open* bundle. Closed bundles are thus incapable of further growth, while open bundles may continue to grow indefinitely.

93. The fibro-vascular bundles of leaves and the reproductive organs are quite generally reduced by the absence

of one or more tissues; this reduction may be so great as to leave but a single tissue, which in many cases is composed of only a few spiral vessels or tracheids (Fig. 32). In other cases, instead of spiral vessels the bundle may consist of a few fibres of bast; or of elongated, thin-walled cells, which are doubtless to be regarded as meristem-cells which failed to fully change into one of the ordinary permanent tissues: this last is a very common accompaniment of reduced bundles.

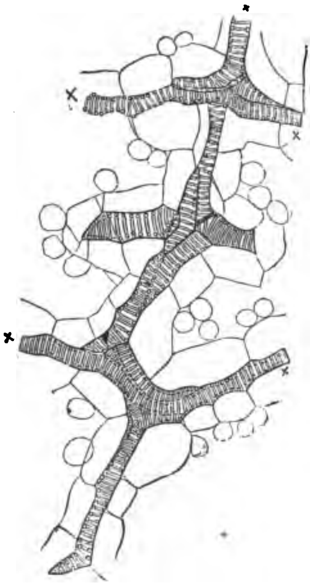


FIG. 32.—Terminal portions of fibro-vascular bundles in a leaf, reduced to tracheids and spiral vessels.

Practical Studies. —(*a*) Break a stem of the Indian corn and note with the naked-eye the tough string-like fibro-vascular bundles which run through the soft tissues. Examine in like manner the fibro-vascular bundles of the common door-yard Plantain.

(*b*) Make a very thin cross-section of the stem of Indian corn and, using the microscope, study the bundles carefully by comparing with Fig. 25. In bundles from young stems the fibrous tissue will not show as good a development as in the figure.

(*c*) Now make thin longitudinal sections of a bundle in such a manner as to have the sections pass through *a* and *i* in the figure. This may be done by slicing the stem in a longitudinal radial direction. Study again by comparison with the figure and with the previous specimen.

(*d*) Make thin longitudinal sections of a bundle at right angles to the last (by longitudinal tangential sections of the stem).

(*e*) Study in like manner the bundles of sugar-cane and asparagus.

(*f*) Study by similar sections the bundles of the young stem of the Castor-oil Plant and Red Clover. The latter is very convenient for study, as the uppermost joints will furnish as young bundles as are required, while lower down all older stages may be obtained. In these note the cambium-zone.

(*g*) Make very thin cross-sections of a root of germinating Indian corn. The first section should be made within a few millimetres of the root-tip. Others should then be made at a greater distance. By staining the specimens with carmine the sieve-regions may be demonstrated better. Note the bundle-sheath.

(*h*) Study in like manner the bundle in the stem of the Club-mosses (some of the species are known as Ground-pines), and if possible make comparison with sections of the smaller Club-mosses (grown in greenhouses often under the name of Lycopodium, although they are in reality species of Selaginella).

(*i*) Dig up the underground stem of the common Brake-fern (Pteris); preserve what is not wanted immediately in alcohol. The bundles may be seen by the naked eye by making a clean cross-cut and examining carefully in the region immediately surrounding the two dark masses of fibrous tissue. Make thin cross-sections and study with the microscope, comparing with Fig. 31. Longitudinal sections in two planes should be made as in *c* and *d* above.

(*j*) Make very thin longitudinal sections of some of the reduced bundles which constitute veins and veinlets of leaves, e.g., in geranium and primrose.

(*k*) Make similar sections of the bundles of petals, e.g., fuchsia.

(*l*) Soak petals of fuchsia for several days in potassic hydrate, then wash in water and carefully mount in pure water. The reduced bundles may generally be well seen by this treatment.

94. **The Fundamental System of Tissues.**—This system includes all the tissues which in any part of a plant frequently make up the bulk of that part, but are not included in the epidermal or fibro-vascular systems. Thus if from any stem, for example, we should strip off the epidermis and then pull out the fibro-vascular bundles, that which remained would be the Fundamental System of Tissues. In those plants (of the lower orders) which have no fibro-vascular bundles everything inside of the epidermis belongs to the fundamental system. On the other hand, in the

stems of our woody trees there is but very little of the fundamental system present, making up the very small pith and the thin plates (medullary rays) running radially through wood and bark.

95. In its fullest development the fundamental system may contain soft tissue (parenchyma) of various forms, thick-angled tissue, stony tissue, fibrous tissue, and milk-tissue. Their arrangement, within certain limits, presents a considerable degree of similarity in nearly related groups of plants, but this is by no means as marked as in the case of the fibro-vascular system.

96. (1) Soft tissue (parenchyma) is the most constant of the fundamental tissues; it makes up the whole of the interior plant-body in those plants where there has been no differentiation into more than one tissue, and it is present in varying amounts in all plants up to and including the highest.

97. (2) Thick-angled tissue (collenchyma) when present, as it generally is in the stems and leaves of flowering plants, is always either in contact with or near to the epidermis.

98. (3) Stony tissue (sclerenchyma) is common beneath the epidermis of the stems and leaves of flowering plants and ferns, and the stems of mosses. It sometimes appears to replace thick-angled tissue. Some elongated forms of stony tissue are scarcely to be distinguished from fibrous tissue.

99. (4) Fibrous tissue occurs in some leaves and stems near to the epidermis. In ferns it forms thick band-like masses, giving strength to the stems.

100. (5) Milk-tissue (laticiferous) may occur, apparently, in any portion of the fundamental system of flowering plants.

101. It is thus seen that in general the tissues of the fundamental system are so disposed that the periphery is harder and firmer than the usually soft interior, although there are many exceptions. This general structure has given rise to the term Hypoderma for those portions of the fundamental system which lie immediately beneath or near to the epidermis. Hypoderma is not a distinctly limited portion—in fact, it is often difficult to say how far it does extend; however, it usually includes several, or even many, layers of cells, or the whole of each of the tissue-masses (e.g., thick-angled, stony, and fibrous tissues, etc.) which immediately underlie the epidermis.

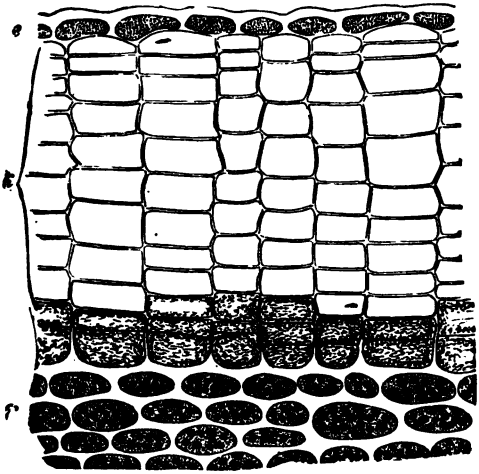


FIG. 33.—Transverse section of one-year-old stem of Ailanthus. *e*, epidermis; *k*, cork-cells; *r*, inner green cells; between *k* and *r* a layer of cells filled with protoplasm, called the phellogen, or cork-cambium. Magnified 350 times.

102. **Cork.**—Within the zone which the hypoderma includes there frequently takes place a peculiar development of the young parenchyma, giving rise to layers of dead

cells, whose cavities are filled with air only. The walls in some cases (e.g., the cork-oak) are thin and weak, while in others (e.g., the beech) they are much thickened, and in all cases they are nearly impermeable to water. True cork is destitute of intercellular spaces, its cells being of regular shape (generally cuboidal) and fitted closely to each other (Fig. 33).

103. Cork-substance is formed by the repeated subdivision of the cells of a meristem layer of the fundamental tissue (Fig. 33); these continue to grow and divide by partitions parallel to the epidermis, forming layers of cork with its cells disposed in radial rows (Fig. 33, *k*). Shortly after their formation the cork-cells lose their protoplasmic contents, while beneath them new cells are constantly being cut off from the cells of the generating layer; in this way the mass of dead cork-tissue is formed and pushed out from its living base.

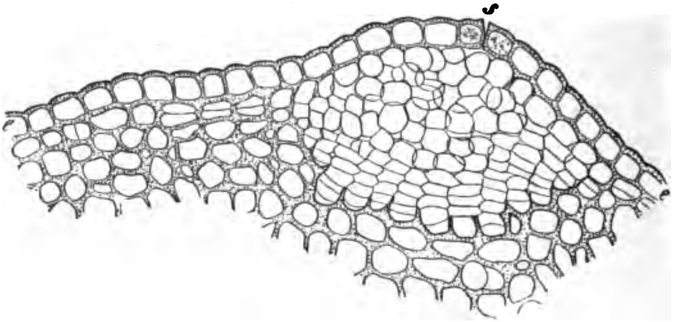


FIG. 34.—Cross-section through a lenticel of Birch. *e*, epidermis; *s*, a breathing-pore. Magnified 280 times.

104. The generating tissue is called the Cork-cambium, or Phellogen; it occurs not only in the hypoderma, but in any other part of the fundamental system, and in the sec-

ondary fibro-vascular bundles. When a living portion of a plant is injured, as by cutting, the uninjured cells beneath the wound often change into a layer of cork-cambium, from which a protecting mass of cork is then developed.

105. A little cork-cambium sometimes forms immediately beneath a breathing-pore, and produces a little mass of cork which pushes out and finally ruptures the epidermis, forming what are called Lenticels (Fig. 34). Lenticels are of frequent occurrence on the young branches of birch, beech, cherry, elder, lilac, etc., and may be distinguished by the naked eye as slightly elevated roughish spots, usually of a different color from the epidermis.

Practical Studies.—(*a*) Make cross-sections of the stem of the pumpkin. Note that the fundamental portion contains only soft and thick-angled tissues.

(*b*) Make a similar section of milkweed (Asclepias) stem. Note that the fundamental portion contains soft, thick-angled, and milk tissue.

(*c*) Make cross and longitudinal sections of the leaf of the Scotch or Austrian Pine. Note the fibrous tissue in the hypodermal portion.

(*d*) The stone-cells in the pith of the apple-twig are good examples of this tissue in the fundamental system.

(*e*) Examine the cells which make up the medullary rays of the old wood of the oak or beech. They will be found to be stony tissue. In young wood they are thin-walled and thus constitute soft tissue (parenchyma).

(*f*) Make very thin sections (in different planes) of commercial cork (the product of the Cork-oak of Southern Europe) and mount in alcohol to expel the air-bubbles. Note the thin walls and the approximately cubical shape of the cells.

(*g*) Make very thin cross-sections of a young twig of the apple, snowball, or birch, so as to cut through a young lenticel. Mount in alcohol as before.

106. **Intercellular Spaces.**—In addition to the cavities and passages which are formed in the plant from cells and their modifications, there are many important ones which

are intercellular and which at no time were composed of cells. In some cases they so closely resemble the cavities derived from cells that it is with the greatest difficulty that their real nature can be made out. In their simplest form they are the small irregular spaces which appear during the rapid growth of parenchyma-cells (Fig. 35); from these to the large regular canals which are common in many water-plants there are all intermediate gradations.

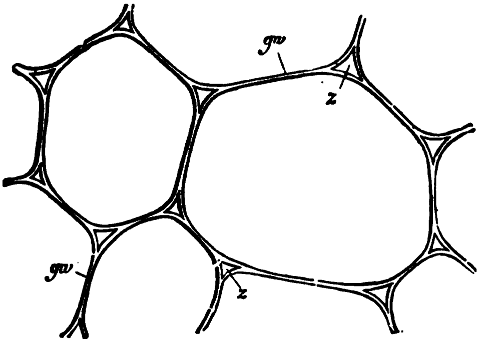


FIG. 35.—A bit of the soft tissue of the pith of the stem of Indian corn; transverse section. *gw*, simple plate of cellulose, forming the partition-wall between two cells; *z*, *z*, intercellular spaces caused by splitting of the walls during rapid growth. Magnified 550 times.

107. In leaves, especially in the soft tissue of the under portion, there are usually many large irregular spaces between the cells; they are in communication with the external air through the breathing-pores, and contain only air and watery vapor. The leaf-stalks and stems of many aquatic plants contain exceedingly large air-conducting intercellular canals, which occupy even more space than the surrounding tissues (Fig. 36). In the rushes, water-lilies, and water-plantains they are so large as to be readily seen by the naked eye. These all are in communication

with the external air through the breathing-pores and the intercellular spaces of the leaves.

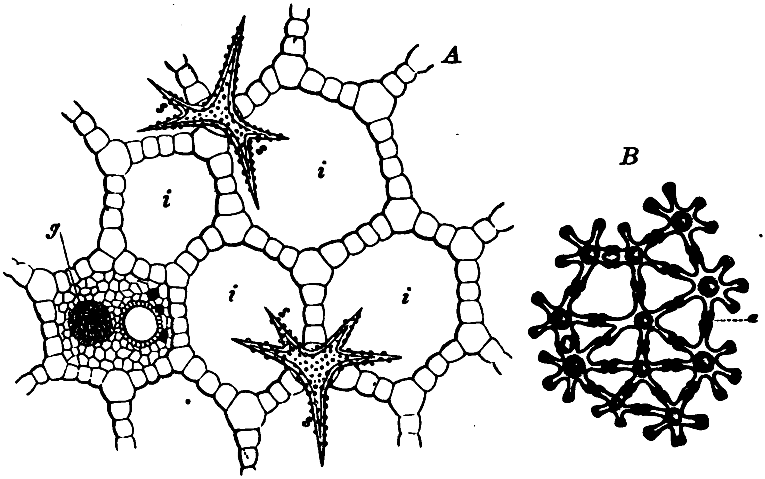


FIG. 36.—Intercellular spaces. *A*, in leaf-stalk of a Water-lily; *s*, star-shaped cells. *B*, in stem of a Rush: the cells here all star-shaped. Both cross-sections.

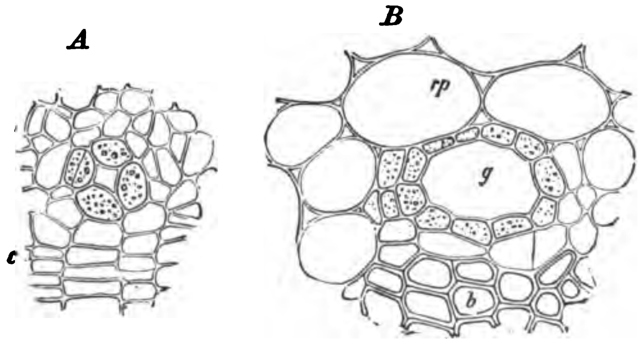


FIG. 37.—Transverse sections of young stem of Ivy (Hedera helix). *A*, young intercellular gum-canal, surrounded by four cells; *c*, cambium; *B*, fully developed canal, *g*; *b*, bast. Magnified 800 times.

108. Some intercellular spaces serve as reservoirs of gum-

my or resinous secretions. Such ones are surrounded by secreting cells which manufacture the gummy or resinous matter and then exude it into the cavity. The Turpentine-canals of the pines and spruces are of this nature, the well-known turpentine being secreted by one or more rows of cells which border the rather large canals. The function of these canals with their secretion has not yet been made out with certainty. The recent suggestion that the turpentine may be for the coating over of wounds is by no means satisfactory.

Practical Studies.—(*a*) Make extremely thin cross-sections of the stem of Indian corn, using a very sharp scalpel (or razor). Note the small triangular intercellular spaces.

(*b*) Make thin cross-sections of an apple-leaf and note the intercellular spaces of the lower half of the section. Remember that in this leaf there are nearly 250 breathing-pores to every square millimetre of lower surface, while there are none at all upon the upper.

(*c*) Study in cross-section the intercellular spaces in the stem of the Rush (Juncus), and the leaf-stalks of water-lilies, water-plantains (Alisma), and arrowheads (Sagittaria).

(*d*) Study turpentine-canals in very thin cross-sections of leaves of pines and spruces. The larger-leaved species, as Scotch, Austrian, or Scrub pine, and the Balsam-fir, are the most satisfactory.

(*e*) Make cross sections of the twigs of White pine and study turpentine canals in bark and wood.

(*f*) Study the oil-receptacles in the fresh rind of the orange and lemon by thin cross-sections. These are not strictly intercellular, but are formed by the breaking away of the secreting cells, thus leaving a cavity.

(*g*) The similarly formed oil-receptacles of the mints and the garden Fraxinella may be studied by making very thin cross-sections of the leaves.

CHAPTER IV.

THE PLANT-BODY.

109. **Generalized Forms.**—The cells, tissues, and tissue-systems described in the preceding pages are variously arranged in the different groups of the vegetable kingdom to form the *Plant-Body*. The simplest plants are single cells or masses of similar cells; in those next higher the cells are aggregated into a few simple tissues; while still above these the tissues are grouped into tissue-systems.

110. With this internal differentiation there is a corresponding differentiation of the external plant-body. The lower plants are not only simpler as to their internal structure, but they are so as to their external form as well. The higher plants are as much more complex than the lower ones as to their external parts as they are in regard to their tissues and tissue-systems.

111. In the lowest groups of plants the simple plant-body has no members; the single- or few-celled seaweed has no parts like root, stem, or leaf; it is a unit as to its external form. In the higher groups, on the contrary, the plant-body is composed of several or many members which are less or more distinct. In those plants in which they first appear, the members are not clearly or certainly to be distinguished from the general plant-body; but.in the higher groups they become distinctly set off, and are eventually differentiated into a multitude of structural and functional forms.

112. Every plant in its earliest (embryonic) stages is simple and memberless; and every member of any of the higher plants is at first indistinguishable from the rest of the plant-body; it is only in the later growth of any member that it becomes distinct; in other words, every member is a modification of, and development from, the general plant-body.

113. Likewise, where equivalent members have a different particular form or function, it is only in the later stages of growth that the differences appear. All equivalent members are alike in their earlier stages, whether, for example, they eventually become broad green surfaces (foliage-leaves), bracts, scales, floral envelopes, or the essential organs of the flower.

114. These facts make it necessary to have some general terms for the parts of the plant-body which are applicable to them in all their forms. We must have, for example, a term so generalized as to include foliage-leaves, bracts, scales, floral envelopes, and all the other forms of the so-called leaf-series. So, too, there is need of a term to include stems, bulb-, bud- and flower-axes, root-stocks, corms, tubers, and the other forms of the so-called stem-series.

115. By a careful study of the members of the more perfect plants we find that they may be reduced to four general forms, viz., (1) *Caulome*, which includes the stem and the many other members which are found to be its equivalent; (2) *Phyllome*, including the leaf and its equivalents; (3) *Trichome*, which includes all outgrowths or appendages of the surface of the plant, as hairs, bristles, root-hairs, etc.; (4) *the Root*, which includes, besides ordinary subterranean roots, those of epiphytes, parasites, etc.

116. As indicated above, in the lower plants the differ-

entiation into members is not so marked as in the higher, and in passing downward in the vegetable kingdom groups are reached in which it is inappreciable, and finally in which it is entirely wanting: such an undifferentiated plant-body is called a *Thallome*, and may properly be regarded as the original form, or prototype.

117. **Thallome.**—The simplest thallome is the single cell; this, though generally rounded, is in some cases irregularly extended into stem-like or leaf-like portions, which may be regarded as, to a certain extent, foreshadowings or anticipations of the members of the higher plants. Plants composed of rows of cells or cell-surfaces frequently show no indication whatever of a division into members; but in some cases there is a little differentiation, which, though not carried far enough to give rise to members, is the same in kind.

118. In the larger seaweeds there is sometimes so much of a differentiation that it becomes difficult to say why certain parts ought not to be called members. Structures of this kind are instructive, as showing that the passage from the thallome plant-body to that in which members are differentiated is by no means an abrupt or sudden one.

119. **Caulome.**—By this general name we designate all axial members of the plant. In the more obvious cases the caulome is the axis which bears leaves (foliage), and in this form it constitutes

(1) The *Stem;* branches are only stems which originate laterally upon other stems.

The other caulome forms are:

(2) *Runners*, which are bract-bearing, slender, weak, and trailing.

(3) *Root-stocks*, which are bract- or scale-bearing, usually weak, and generally subterranean.

(4) *Tubers*, which are bract- or scale-bearing, short and thickened, and subterranean.

(5) *Corms*, which are leaf-bearing, short and thickened, and subterranean.

(6) *Bulb-axes*, which are leaf-bearing, short and conical, and subterranean.

(7) *Flower-axes*, which are bract-, perianth-, stamen-, and pistil-bearing, short and usually conical and aerial.

(8) *Tendrils*, which are degraded, slender, aerial caulomes, nearly destitute of phyllomes.

(9) *Thorns*, which are degraded, thick, conical, aerial caulomes, nearly destitute of phyllomes.

120. **Phyllome.**—The phyllome is always a lateral member upon a caulome. It is usually a flat expansion and extension of some of the tissues of the caulome. Its most common form is

(1) The *Leaf* (foliage), which is usually large, broad, and mainly made up of chlorophyll-bearing tissue.

The other phyllome forms are:

(2) *Bracts*, which are smaller than leaves, generally green.

(3) *Scales*, which are usually smaller than leaves, wanting in chlorophyll-bearing tissue, and generally with a firm texture.

(4) *Floral envelopes*, which are variously modified, but generally wanting in chlorophyll-bearing tissue, and with generally a more delicate texture.

(5) *Stamens*, in which a portion of the soft tissue develops male reproductive cells (pollen).

(6) *Carpels*, bearing or enclosing female reproductive organs (ovules).

(7) *Tendrils* and (8) *Spines*, which are reduced or degraded forms, composed of the modified fibro-vascular bundles and a very little soft tissue; in the first the structures are weak and pliable, in the latter stout and rigid.

The altogether special modifications of the phyllome, as in *pitchers* and *cups*, will be noticed hereafter.

121. **Trichome.**—The trichome is a surface appendage consisting of one or more cells usually arranged in a row or a column, sometimes in a mass. Its most common forms are met with in

(1) The *Hairs* of many plants. (See page 36.)

The other trichome forms are:

(2) *Bristles*, each consisting of a single pointed cell or a row of cells, whose walls are much thickened and hardened.

(3) *Prickles*, like the last, but stouter, and usually composed of a mass of cells below.

(4) *Scales*, in which the terminal cell gives rise by fission to a flat scale, which soon becomes dry.

(5) *Glands*, which are generally short, bearing one or more secreting cells.

(6) *Root-hairs*, which are long, thin, single-celled (in mosses a row of cells), and subterranean.

(7) *Sporangia* of ferns and their relatives, some of whose interior cells develop into reproductive cells (spores).

(8) *Ovules* of flowering plants one or more of whose cells develop into reproductive cells (embryo-sacs).

122. **Root.**—The root is that portion of the plant-body which is clothed at its growing point with a root-cap. In ascending through the vegetable kingdom roots are the latest of the generalized forms to make their appearance, and in the embryo they appear to be formed later than

caulome and phyllome. They present fewer variations than any of the other generalized forms. The ordinary

(1) *Subterranean roots* of plants are typical. They differ but little from one another in whatever plants they may be found.

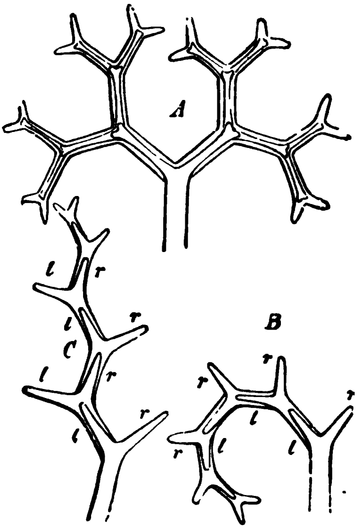


FIG. 38.

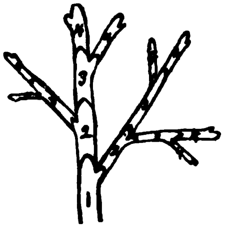


FIG. 39.

FIG. 38.—Diagrams of dichotomous branching. *A*, normal dichotomy, in which each branch is again dichotomously branched; *B*, helicoid dichotomy, in which the right-hand branch, *r*, does not develop further, while the left-hand one, *l*, is in every case again branched; *C*, scorpioid dichotomy, in which the branches are alternately further developed.

FIG. 39.—Diagram of botryose monopodial branching. The numerals indicate the "generations."

The other root-forms are:

(2) *Aerial roots*, which project into the air, and often have their epidermis peculiarly thickened, as in the epiphytic orchids.

(3) *Roots of Parasites*, which are usually quite short,

and in some cases provided with sucker-like organs, by means of which they absorb food from their hosts.

123. **General Modes of Branching of Members.**—All the members of the plant-body may branch. This branching always follows one of two general methods. In the one the apex of the growing member divides into two new growing points, from which branches proceed: this is the *Dichotomous* mode of branching (Fig. 38). In the other the new growing points arise laterally while the original apex still retains its place and often its growth: this is the *Monopodial* mode of branching (Fig. 39). Both modes are subject to many modifications, the most important of which are briefly indicated in the following table; and moreover a member may branch for a time dichotomously and then monopodially, or the reverse.

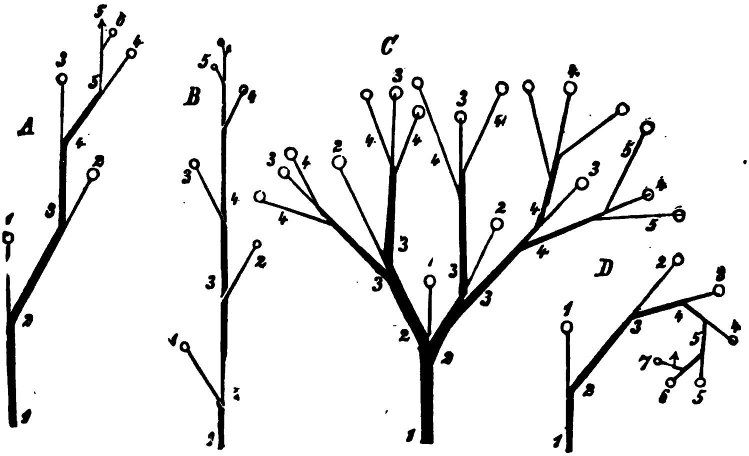


FIG. 40.—Diagrams of cymose monopodial branching. *A* and *B*, scorpioid cymes; *C*, forked cymose monopodium, the compound or falsely dichotomous cyme (called also the *dichasium*): *D*, helicoid cyme.

A. DICHOTOMOUS.

1. *Forked dichotomy*, in which both branches of each bifurcation are equally developed (Fig. 38, *A*).
2. *Sympodial dichotomy*, in which one of the branches of each bifurcation develops more than the other.
   - *a*. *Helicoid sympodial dichotomy*, in which the greater development is always on one side (Fig. 38, *B*).
   - *b*. *Scorpioid sympodial dichotomy*, in which the greater development is alternately on one side and the other (Fig. 38, *C*).

B. MONOPODIAL.

1. *Botryose monopodium*, in which, as a rule, the axis continues to grow, and retains its ascendency over its lateral branches (Fig. 39).
2. *Cymose monopodium*, in which the axis soon ceases to grow, and is overtopped by one or more of its lateral branches.
   - *a*. *Forked cymose monopodium*, in which the lateral branches are all developed (Fig. 40, C).
   - *b*. *Sympodial cymose monopodium*, in which some of the lateral branches are suppressed; this may be—
     - *b'*. Helicoid, when the suppression is all on one side (Fig. 40, *D*); or—
     - *b''*. Scorpioid, when the suppression is alternately on one side and the other (Fig. 40, *A* and *B*).

Practical Studies.—(*a*) Mount and examine under a low power of the microscope or by the naked eye alone the following in order as examples of thallomes: 1, Green Slime; 2, Pond Scum; 3, the first stage of a fern "seedling" (little flat green growths, 3–5 mm. across, which often appear on the earth near ferns in greenhouses); 4, Sea-lettuce (Ulva); 5, Irish moss (Chondrus), the latter showing a much-lobed form.

(*b*) Study as examples of caulome forms the following in order 1, the stem of Lamb's Quarters, or Indian corn; 2, runners of the strawberry; 3, root-stocks of blue grass; 4, tubers of the potato; 5, corms of Gladiolus, or Indian turnip; 6, bulb-axis of the onion; 7, flower-axis of anemone, buttercup, tulip, or lily; 8, tendrils of the grape, or Virginia creeper; 9, thorns of honey-locust, or plum.

(*c*) Study as examples of phyllome forms: 1, leaf of apple, cherry, or Indian Corn, etc.; 2, bracts of flower-cluster of cress, sweet-william, golden-rod, or aster; 3, scales of buds of hickory or lilac; 4, floral envelopes of anemone, buttercup, tulip, or lily; 5, stamens of any of the above; 6, carpels of anemone, buttercup, columbine, etc.; 7, tendrils of pea, or vetch; 8, spines of thistles.

(*d*) Study as examples of phyllome forms: 1, hairs of petunia or verbena; 2, bristles of tickle-grass; 3, prickles of the hop; 4, scales of the buffalo-berry, or elæagnus; 5, glands of the petunia or walnut; 6, root-hairs of seedling cabbages, radishes, etc.; 7, sporangia of common polypody fern; 8, ovules of anemone, buttercup, columbine, bouncing-bet, etc.

(*e*) Study for root-forms: 1, roots of seedling cabbages, radishes, etc.; 2, aerial roots of greenhouse orchids; 3, parasitic roots of dodder or mistletoe.

CHAPTER V.

THE CHEMISTRY AND PHYSICS OF PLANTS.

124. **The Water in the Plant.**—All living parts of plants are abundantly supplied with water. It is always present in living protoplasm, and the greater its activity the more watery is its composition. The cell-walls of living tissues also contain large quantities of water ; and in plants composed of many cells (as the larger flowering plants) even those cells and tissues which have lost their activity generally have their walls saturated with water. In ordinary herbaceous land-plants the amount of water is not far from 75 per cent of their whole weight. In aquatic plants the percentage is much higher, often exceeding 95 ; it is so abundant in many of the simpler forms that upon drying nothing but an exceedingly thin and delicate film is left.

125. **Water in the Protoplasm.**—As explained in paragraph 4 (page 2), living protoplasm has the power of imbibing water and thereby of increasing its fluidity. Even after it has imbibed all the water which it can retain it continues the process, and separates the surplus in drops in its interior—the so-called vacuoles. Now an examination of the cells of rapidly growing tissues shows that their protoplasm is much more watery than that of living but dormant tissues—e.g., those of seeds—and one of the first signs of activity in the latter is the imbibition of water.

126. This avidity of protoplasm for water plays an important part in the general economy of the plant. By it all the cells which contain protoplasm are kept turgid, and by the tension thus created the soft parts of plants are made rigid. It plays no small part also in keeping up the supply of moisture in living tissues when wasted by evaporation.

127. **Water in the Cell-Walls.**—According to Nägeli's theory, the wall of the cell is not a membrane which separates the water of one cell-cavity from that in the next, but rather a pervious stratum, composed of solid particles (molecules) which are not in contact, and between which the water freely passes. In a living tissue the water is continuous from cell to cell, and constantly tends to be in equilibrium —i.e., the turgidity of the cells is approximately equal throughout the tissue, and likewise the wateriness of both cell-walls and cell-contents.

128. In the simpler aquatic plants the water of the cells and their walls is continuous with that in which they grow. Likewise the water in the tissues of roots or other absorbing organs of the higher aquatic plants is continuous with that which surrounds them; and even in ordinary terrestrial plants there is a perfect continuity of the water in the root-tissues with the moisture of the soil.

129. **The Equilibrium of the Water in the Plant.**—The water in the tissues of every plant tends constantly to become in equilibrium, and this state would soon be reached were it not for certain disturbing causes which are almost as constantly in action. In any cell an equilibrium may soon be reached between the two forces which reside respectively in the cell-wall and the protoplasm, viz., (1) the attraction of the surfaces of the molecules for the water,

and (2) the "imbibition-power" of protoplasm. So, too, an equilibrium between cell and cell may soon be reached. This equilibrium once attained, all motion of the water must cease, and it must remain at rest until disturbed by some other force or forces. This condition, or one approximating very closely to it, is reached by many of the perennial plants during the winter or period of rest.

130. **Disturbance of Equilibrium.**—During the growing stages of plants the equilibrium of the water is constantly disturbed in one or more ways, viz., (1) by the chemical processes within the cells; (2) by the "imbibition-power" of the protoplasm and walls of newly formed cells; (3) by the evaporation of a portion of the water.

131. The chemical processes within the cell include: (1) the actual use of water by breaking it up into hydrogen and oxygen; every molecule which is so broken up leaves a vacancy which, sooner or later, must be replaced; (2) the formation of substances which are more soluble than those from which they were formed; (3) the formation of substances which are less soluble than those from which they were formed. These processes take place in all cells, even those of the simplest plants.

132. In plants composed of tissues, wherever new cells are forming and developing, the new protoplasm and cell-walls require considerable quantities of water to satisfy their molecular attraction; this supply is always made in part or entirely at the expense of the adjacent cells. In many aquatic plants there can be little doubt that the needed water in growing tissues is obtained partly by direct absorption from the surrounding water, but this can only be the case with the external cells; the deep-lying ones must obtain their supply from the cells which surround them.

In aerial parts of plants the newly formed cells obtain all their water from the adjacent cells.

133. **Evaporation of Water.**—In the aerial parts of plants the evaporation of water from their surfaces is a far more powerful disturbing cause than either of the two preceding. Whenever a cell is exposed to dry air at ordinary temperatures a portion of its water passes off by evaporation; this immediately disturbs the equilibrium of water throughout the tissue, and the more rapid or the longer continued the evaporation the greater the disturbance.

134. Evaporation from living cells or tissues is dependent upon a number of conditions, some of which are entirely exterior, while others are connected with the structure of the plant itself. Among the former, the most important is the condition of the air as to the amount of moisture which it contains. In air saturated with moisture no evaporation can take place; but whenever the amount of moisture falls below the point of saturation, if the other conditions are favorable, evaporation takes place.

135. The temperature of the air (and, as a consequence, that of the plant also) has some effect upon the rapidity of evaporation. It appears that there is an increase in the amount of water given off as the temperature rises; this may be due, however, to the fact that with such increase of the temperature of the air there is generally a considerable decrease in its moisture. The direct influence of light upon evaporation is also somewhat doubtful. While there can be no doubt that plants generally lose more water in the light than in darkness, it appears to be due to the increased heat and dryness which are common accompaniments of the increase of light.

136. In enumerating the internal conditions, one general

condition must not be forgotten, viz., that the water in plant-cells contains many substances in solution, and consequently evaporates less rapidly than pure water, in accordance with well-known physical laws. Moreover, the attraction of the substance of the cell-walls for the water counteracts, to a considerable extent, the tendency to evaporation; and in the same manner, even to a greater extent, the water is prevented from passing off by the "imbibition-power" of protoplasm. It is, in fact, impossible to deprive cellulose and protoplasm of all their water in dry air at ordinary temperatures.

137. In all the aerial parts of higher plants the epidermis offers more or less resistance to the escape of the water of the underlying tissues. This is mainly accomplished by the thick outer wall of the epidermal layer; in many cases, especially in plants growing naturally in very dry regions, the epidermis consists of several layers of cells, which offer still more resistance to evaporation by being themselves filled with moist air only.

138. Among the lower plants, the single reproductive cells (spores) are guarded against the loss of water by having their walls greatly thickened. Even in the lowest plants, the Slime Moulds, the naked masses of protoplasm, when placed in dry air, will contract into rounded masses, which then become covered with a somewhat impervious envelope.

139. The breathing-pores of the green and succulent parts of higher plants control to a great extent the amount and rapidity of their exhalation. Breathing-pores are placed over intercellular spaces, which are in communication with the intercellular passages of the plant. These spaces and passages are filled with moist air and gases,

which, when the breathing-pores are open, expand and contract with every change of temperature or atmospheric pressure, and thus permit the escape of considerable amounts of water; when, on the other hand, the breathing-pores are closed, little or no escape of moisture is possible.

140. The opening and closing of the breathing-pores appear to depend upon the amount of light; they open more widely the greater the amount of light, and close almost completely in darkness. The amount of moisture on the surface of the epidermis appears also to affect somewhat the opening and closing of the breathing-pores; when the epidermis is very dry they are generally closed, and *vice versa.*

141. **The Amount of Evaporation.**—The conditions controlling evaporation are thus seen to be many and various. They never, or but very rarely, act singly, two or more of them usually acting together with varying intensity, so that the problem of the amount of evaporation taking place at any particular time is a complex and difficult one. All the observations yet made, and which have necessarily been upon a very small scale, indicate that the rate of evaporation is actually very slow.

142. A given area of leaf-surface will evaporate much less water than an equal area of water-surface. The amount of the former has been estimated at from one seventeenth to one third of the latter, varying of course in different plants. A grape-leaf has been found to evaporate in twelve hours of daylight an amount of water equal to a film covering the leaf only .13 mm. (.005 in.) deep; a cabbage-leaf for the same time .31 mm. (.012 in.); an apple-leaf .25 mm. (.01 in.). An oak-tree was found to have evaporated in one season, during the time it was covered with foliage, an

amount of water equal to a layer 33 mm. (about 1⅓ in.) deep over all its leaf-surface. When we remember that the usual evaporation from a water-surface for the same period is from 500 to 600 or more millimetres (20 to 25 in.) we must conclude that leaves, instead of being organs for increasing evaporation, are able to successfully resist evaporation.

143. **The Movement of Water in the Plant.**—It is clear, from what has been said, that in many-celled plants there must be a considerable movement of water in some parts, to supply the loss by evaporation. Thus in trees there must be a movement of water through the roots, stems, and branches to the leaves, to replace the loss in the latter. This is so evident that it scarcely needs demonstration; it can, however, be shown by cutting off a leafy shoot at a time when evaporation is rapid; in a short time the leaves wither and become dried up, unless the cut portion of the shoot be placed in a vessel of water; in the latter case the water will pass rapidly into the shoot, and the leaves will retain their normal condition. If in such an experiment a colored watery solution (as of the juice of Poke-berries) be used instead of pure water, it will be seen that the liquid has passed more abundantly through certain tracts than through others, indicating that the tissues are not equally good as conductors of watery solutions.

144. As would readily be surmised, the tissues in ordinary plants which appear to be the best conductors are those composed of elongated wood-cells, and it is doubtless through them that the greater part of the water passes. Furthermore, it is probable that the movement of the water is through the substance of the cell-walls, and not, at least to any great extent, through the cell-cavities. According

to this view, the force which raises the water, in some cases to the height of a hundred metres or more, is the attraction of the surfaces of the cellulose molecules for the layers of water which surround them.

145. The rapidity of the upward movement of water varies greatly in different plants and under different conditions. In a silver-poplar a rate of 23 cm. (9 in.) an hour has been observed; in a cherry-laurel 101 cm. (40 in.); and in a sunflower 22 metres (72 feet).

ADDITIONAL NOTES on the movement of water in the plant.

I. *Root-Pressure.*—If the root of a vigorously growing plant be cut off near the surface of the ground and a glass tube attached to its upper end, the water of the root will be forced out, often to a considerable height. Hales more than a hundred and fifty years ago observed a pressure upon a mercurial gauge equal to 11 metres (36.5 ft.) of water when attached to the root of a vine (Vitis). Clark (1873), in a similar manner, found the pressure from a root of a birch (Betula lutea) to be equal to 25.8 metres (84.7 ft.) of water. This root-pressure appears to be greatest when the evaporation from the leaves is least; in fact, if the experiment is made while evaporation is very active, there is always for a while a considerable absorption of water by the cut end of the root, due probably to the fact that the cell-walls had been to a certain extent robbed of their water by the evaporation from above. Root-pressure is probably a purely physical phenomenon, due to a kind of endosmotic action taking place in the root-cells.

II. *The Flow of Water* (sap) from the stems and branches of certain trees, notably from the sugar-maple, appears to be due to the quick alternate expansion and contraction of the air and other gases in the tissues from the quick changes of temperature. The water is forced out of openings in the stem when the temperature suddenly rises; when the temperature suddenly falls, as at night, there is a suction of water or air into the stem. When the temperature is nearly uniform, whether in winter or summer, there is no flow of sap.

III. *No Circulation of Sap.*—While there is an upward movement of the water in plants because of the evaporation from the leaves, there is no downward movement as has been popularly supposed. The "circulation of the sap," in the sense that there is an upward stream in one portion of the plant and a corresponding downward stream in another, does not exist. Likewise, the belief still maintained by some people that in the autumn or early winter "the sap goes down into the roots," and that "it rises" in the spring, is entirely erroneous. There is actually more water (sap) in an ordinary deciduous tree in the winter than there is in the spring or summer (excluding of course the new and very watery growths).

Practical Studies.—A few physiological experiments may be easily made by the student. The following will serve as a beginning:

(*a*) Collect a quantity of green grass in the middle of the day when it is not wet; weigh it accurately, then thoroughly dry it in an oven, being careful not to scorch it. Weigh again: the difference in the two weighings will be approximately the amount of water in the living plant, although some water will still be left in the plant by ordinary drying.

(*b*) Weigh a handful of beans; put them into warm water or moist earth for a day or two until they are beginning to sprout. Then gather them up carefully, wipe off all external dirt and moisture, and weigh again. Here the difference will be approximately the amount of water absorbed by the protoplasm.

(*c*) Place some specimens of Green Slime or Pond Scum on a dry glass slip, using no cover-glass. Note with the microscope the rapid evaporation of water as shown by the collapsing of the cells.

(*d*) Gather fresh leaves of clover; suspend some of them under a bell-jar or inverted tumbler which stands in a plate containing a little water. Put the other leaves into a dry plate with no protection from the dry air. Note that the evaporation is very much more rapid in the dry air than in the moist air under the bell-jar.

(*e*) Strip off the epidermis from a leaf (hyacinth, live-for-ever, etc., are good) and note that the evaporation is much greater (as shown by the more rapid wilting) than from the uninjured leaf. This shows that the epidermis and its breathing-pores retard evaporation.

(*f*) Lilac-leaves have breathing-pores upon their lower surfaces alone. Provide two leaves: cover the lower surface of one with a thin coat of varnish, which will prevent evaporation through the breathing-pores; suspend both in a current of dry air, and note that the one not varnished withers sooner than the other.

(*g*) Cottonwood-leaves have breathing-pores upon both surfaces. Repeat experiment above (*f*).

(*h*) Procure a well-grown geranium (20 to 25 cm. high) in a flower-pot. Cover the pot with a piece of thin sheet-rubber, tying it carefully around the stem of the plant. Insert a short tube (provided with a cork) at the proper place, through which to introduce water.

Weigh the whole at intervals of a few hours. The loss will be the amount of evaporation (approximately). By adding weighed quantities of water at intervals the experiment may be continued indefinitely.

(*i*) Cut off a rapidly growing leafy shoot of the apple or geranium and place the lower end in a bottle of water. Close the bottle by pressing soft wax into the mouth of the bottle around the stem. On account of the upward movement of the water through the shoot its level in the bottle will be perceptibly lowered. This will be more evident the smaller the diameter of the bottle.

(*j*) Cut off the stem of a rapidly growing sunflower a couple of inches above the ground; slip over it the end of a tightly fitting india-rubber tube 8 to 10 cm. long. Slip into the other end a small glass tube 5 to 10 mm. in diameter, being sure to make the joints water-tight. The "root-pressure" will cause the water to rise into the vertical tube. Note the effect of a change of temperature of the soil.

(*k*) Cut off a small branch of a maple-tree on a cold winter day; bring it into a warm room. As soon as the temperature of the branch rises, the sap (water) will begin to flow from the cut surface. Lower the temperature and the flow will cease; raise it again and the flow will be resumed.

146. **Plant-Food.**—The most important elements which are used in the nutrition of plants, or which, in other words, enter into their food, are Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Iron, and Potassium. These all appear to be necessary to the life and growth of the plant, and if any of them are wanting in the water, soil, or air from which the plant derives its nourishment, death from starvation will soon follow.

147. There are other elements which are made use of by plants, but, as life may be prolonged without them, they are regarded as of secondary importance. In this list are Phosphorus, Calcium, Sodium, Magnesium, Chlorine, and Silicon.

148. **The Compounds Used.**—With the single exception of oxygen, the elementary constituents named above do not enter into the food of plants in an uncombined state; on

the contrary, they are always absorbed in the condition of compounds, as water, carbon dioxide, and the

Nitrates	of	Ammonia.
Sulphates		Potash.
Carbonates		Lime.
Phosphates		Iron.
Silicates, or		Soda, or
Chlorides		Magnesia.

Of the last the nitrates of potash and ammonia, sulphate of lime, carbonates of ammonia and lime, are probably to be considered as the most important for ordinary plants. Water is necessary for all plants, and carbon dioxide for those which are green.

149. In addition to the foregoing many organic compounds are absorbed in particular cases, as in those plants which live in decaying animal or vegetable matter (saprophytes), as well as those which absorb the juices from living plants (parasites).

150. **How the Food is Obtained.**—In the case of aquatic plants these compounds are taken into the plant-body by a process of diffusion from the surrounding water; in terrestrial plants the gaseous compounds, as carbon dioxide and carbonate of ammonia, are absorbed—at least in part—by the leaves directly from the surrounding air, while the solutions of these and the other compounds in the water in the soil find their way into the plant by diffusion. The water of streams and ponds and that found in moist soil generally contains, in addition to decayed vegetable matter, greater or less quantities of sulphate, carbonate, and phosphate of lime, nitrates of potash and ammonia, besides small amounts of iron, silica, and chlorine. Plants flourish best when these constitute (in the aggregate) one part in one thousand parts of water.

151. **How the Food is Transported in the Plant.**—Once within the plant-body, the food-materials diffuse to all watery parts, in the case of the larger terrestrial plants rising through the stem to the leaves. By diffusion there is a constant tendency toward an equal distribution throughout the plant of the solutions which enter it; and if there were no disturbing chemical reactions taking place, such a condition would in most plants be soon reached. It is quite probable, indeed, that this actually happens for certain substances which are found in solution in the soil or water, and which, entering plants, diffuse through them to all parts, but not being used they soon reach a state of equal diffusion, which is only slightly disturbed by the extension of the plant-body by growth. The diffusion of food-materials throughout terrestrial plants is aided by the evaporation of water from the leaves, thus causing a strong upward movement of the water which contains the various solutions of food-matter; but it is not dependent upon evaporation, for diffusion takes place under conditions which preclude evaporation.

152. **Starch-making, or Assimilation.**—Most of the food-materials of plants can be directly used by the protoplasm. Thus the oxygen and water, and the nitrates, sulphates, etc., mentioned above may be at once made use of by the protoplasm for its own nourishment. It is not so, however, with the carbon dioxide. It cannot be used directly as food, but must first undergo a special preparation. It must be broken up and recombined along with the elements derived from water so as to form a new compound which the protoplasm can digest. This new compound is starch, or something much like it, and so we may call this prepara-

tory process the Starch-making process, or, as it is known in botanical books, Assimilation.

153. We cannot yet give an exact account of the successive steps in the manufacture of starch. The principal facts, however, are as follows: Carbon dioxide contains Carbon (C) and Oxygen (O) in the proportion of one atom of the former to two of the latter—(CO_2). Water contains Hydrogen (H), two atoms, and Oxygen (O), one atom—(H_2O). Both water and carbon dioxide are decomposed in the chlorophyll-granules of leaves and other green parts of plants. After decomposition there is such a recombination as to produce Starch ($C_{12}H_{20}O_{10}$).

154. The carbon dioxide is probably decomposed into carbon oxide (CO) and free oxygen (O): thus $CO_2 = CO + O$. At the same time water is decomposed into hydrogen and oxygen: thus $H_2O = 2H + O$. The free oxygen-atoms are exhaled from the plant, and by the union of carbon oxide and hydrogen the starch is formed: this appears as minute granules imbedded in the chlorophyll-bodies.

155. These chemical changes may be shown as follows:

$$\left.\begin{array}{rl} 12CO_2 = & \left\{ 12CO \ldots\ldots\ldots\ldots\ldots \right. \\ & \left.\begin{array}{l} 12O \\ 12O \end{array}\right\} = 24O \text{ set free.} \\ 12H_2O = & \left\{ 24H \ldots\ldots\ldots\ldots\ldots\ldots \right. \end{array}\right\} = \overset{\text{starch}}{C_{12}H_{20}O_{10}} + 2H_2O.$$

Here twelve molecules of carbon dioxide and twelve molecules of water produce one molecule of starch and two molecules of water (water of organization), while twenty-four atoms of oxygen are set free and permitted to escape from the cells into the surrounding air or water.

In some plants no starch is formed in the chlorophyll, but oily or sugary matters which have nearly the same chemical significance.

156. This decomposition and subsequent combination take place only in the granules or masses of chlorophyll, and only in sunlight. Those parts of ordinary plants which are destitute of chlorophyll are entirely wanting in the power of starch-making (assimilation), and likewise the chlorophyll-bearing portions are unable to assimilate in darkness.

157. **Digestion and Use of Starch.**—In darkness the starch which had previously formed in the chlorophyll-bodies undergoes changes which render it soluble, allowing it to diffuse to other parts of the plant with great freedom. The nature of these changes appears to vary somewhat in different plants, but they consist essentially in the change of the insoluble starch into a chemically similar but soluble substance. Glucose ($C_{12}H_{24}O_{12}$), inulin ($C_{12}H_{20}O_{10}$), and cane-sugar ($C_{12}H_{22}O_{11}$) are the more common of the soluble substances so formed, and one or other of these may frequently be detected in the adjacent cells after the disappearance of the starch from the chlorophyll.

158. These diffusing assimilated matters are imbibed by the protoplasm of the living tissues, and constitute its most important food. In connection with the nitrates and sulphates, etc., also imbibed, it furnishes the materials for the increase of protoplasmic substance in growing cells.

159. **The Storing of Reserve Material.**—In many plants the surplus starch is stored up in one or more organs as reserve material; thus in the potato the starch formed in the leaves in sunlight is, in darkness, transformed into glucose, or a substance very nearly like it, and in this soluble form it is diffused throughout the plant, and in the underground stems (tubers) is again transformed into starch. So in the case of many seeds a mass of reserve material is stored up,

generally in the form of starch (e.g., the cereal grains), and sometimes in the form of oily matters (e.g., the seeds of mustard, flax, castor-bean, squash, etc.).

160. **The Use of Reserve Material.**—In the use of reserve material, as in the germination of starchy seeds, the starch appears to undergo a change exactly like that in its disappearance from chlorophyll. Here it is certain that oxygen is absorbed, and that carbon dioxide is evolved, while the starch is transformed into glucose. Similar transformations doubtless take place in the use of the starch stored up in buds, twigs, stems, bulbs, etc.

161. In the germination of oily seeds, after the absorption of oxygen, starch is (in many cases, at least) first produced, and from this the soluble sugar is formed. In any case, after the solution is attained the subsequent changes are similar to those which follow the transformation of the starch of the chlorophyll.

162. **The Nutrition of Parasites and Saprophytes** is similar to that of embryos, buds, bulbs, etc. Here assimilated materials are drawn from some other organism, and subsequently undergo digestive changes. In some cases the parasitism is only partial, as in the mistletoe, where a part of the assimilated matter is formed in the parasite (which, therefore, contains chlorophyll), while a portion seems to be taken, along with the mineral salts, from the host-plant. So, too, there are plants which are partially saprophytic in habit, deriving a part of their nourishment as saprophytes, while the remainder is elaborated by their chlorophyll.

163. Many cultivated plants, as we grow them, are partially saprophytic, deriving a portion of their nourishment from decaying organic matter in the soil. The so-called

carnivorous plants, as the sundews (Drosera), fly-trap (Dionæa), pitcher-plants (Sarracenia), etc., are in reality partially saprophytic, obtaining a considerable part of their food-materials from decaying animal matter.

164. For convenience the various processes which take place in the digestion of starch, the storing of reserve material, the use of other food-matters, etc., have all been included under one general term—Metastasis, or Metabolism. It has been made to include all chemical changes in the plant excepting assimilation (starch-making). Assimilation and metastasis thus include all chemical changes taking place in green plants. In all plants there is metastasis, while assimilation is present in those only which contain chlorophyll.

165. **Alkaloids and Acids.**—Among the most obscure of the metastatic changes are those which give rise to the alkaloids. These are compounds of carbon, hydrogen, nitrogen, and generally oxygen, as follows:

Nicotine ($C_{10}H_{14}N_2$), found in tobacco.
Cinchonia ($C_{20}H_{24}N_2O$), found in Peruvian bark.
Morphia ($C_{17}H_{19}NO_3 + H_2O$), found in the opium-poppy.
Strychnia ($C_{21}H_{22}N_2O_2$), found in the seeds of Strychnos.
Caffeine ($C_8H_{10}N_4O_2 + H_2O$), found in coffee and tea.

166. These and many others occur in plants in combination with organic acids, such as malic acid ($C_4H_6O_5$); tartaric acid ($C_4H_6O_6$); citric acid ($C_6H_8O_7$); oxalic acid ($C_2H_2O_4$); tannic acid ($C_{27}H_{22}O_{17}$); quinic acid ($C_7H_{12}O_6$); meconic acid ($C_7H_4O_7$). These acids are probably formed by the oxidation of some of the sugary or starchy substances in the plant, while the alkaloids with which they are combined appear to have some relation to the nitrogenous constituents of the protoplasm.

167. From the fact that the alkaloids are formed more abundantly in those tissues which have passed the period of their greatest activity, it may be surmised that they are either compounds of a lower grade than the ordinary albuminoids, or the first results of the incipient decay of the cells.

168. **Results of Assimilation and Metastasis.**—In the preceding paragraphs we have found that chlorophyll-bearing plants absorb carbon dioxide and exhale free oxygen, the former being decomposed in the chlorophyll-granules in sunlight, and the oxygen being set free as a consequence. In other words, the absorption of carbon dioxide and the exhalation of oxygen are connected with the process of assimilation.

169. Now, it may be shown that oxygen is absorbed and carbon dioxide evolved, as results of certain metastatic processes which take place in any tissues, whether possessing chlorophyll or not, and independently of the presence or absence of sunlight. In the sunlight the absorption of carbon dioxide to supply assimilation is so greatly in excess of its exhalation, as a result of metastatic action, that the latter is unnoticed. In darkness, however, when assimilation is stopped, the exhalation of carbon dioxide becomes quite evident.

170. So, too, with oxygen: in the sunlight the excess of its evolution from assimilation is so great over its absorption for metastasis that the latter was long unknown; but in the absence of light its absorption becomes manifest. Parasites and saprophytes, as well as those parts of ordinary plants which are wanting in chlorophyll, as flowers and many fruits, deport themselves in this regard exactly as chlorophyll-bearing organs do in darkness.

Practical Studies.—(*a*) Put a dry apple-twig into a short piece of gas-pipe, closing the ends, not very tightly, with clay; put it into a fire and heat to redness. The carbon left will be of the form, and about half the weight, of the dry twig.

(*b*) Germinate several kernels of Indian corn in moist sand, and when the roots are two to four centimetres long transfer the plants to wide-mouthed bottles or jars, supporting them as in Fig. 41. Fill one of the jars with pure (distilled) water; fill a second with well-water (which always contains many, if not all, of the materials of plant-food); fill a third with water from a stream or pond (which also always contains all, or nearly all, the materials of plant-food). Notice that the plants will grow in all the jars, as all are supplied with carbon dioxide and water, the most important plant-food; but the best and longest-continued growth takes place in the second and third jars.

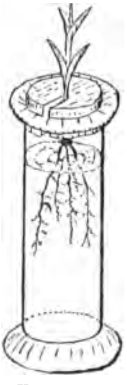


FIG. 41.—Showing method of making water-culture experiments.

(*c*) In case the materials can be obtained, fill a fourth jar (as in the previous experiment) with a solution of the following constitution:

Distilled water	1000	parts
Phosphoric acid	0.13	"
Lime	0.16	"
Potash	0.14	"
Magnesia	0 02	"
Sulphuric acid	0.03	"
Nitric acid	0.46	"
Chlorine	0.001	"
Sulphate of iron	0.001	"

With this solution perfect plants may be grown, if care be taken to renew the solution from time to time.

(*d*) Secure a quantity of Pond Scum (Spirogyra) in a dish of water; expose it to the sunlight for some hours, and then examine it for starch with the aid of the microscope, making use of the iodine test. When starch has certainly been found, put the dish in a dark (but not cool) chamber, and after some hours repeat the foregoing examination. No starch will now be found.

(*e*) Select two thrifty potato-plants of about equal size and about the period of flowering, when the tubers are beginning to grow; cover one with a tight box or barrel, so as to shut off all the light and prevent starch-making. At the expiration of a fortnight examine and compare the tubers of the two plants.

(*f*) Germinate a handful of Indian corn in moist clean sand, and, as the plants grow, taste the kernels from time to time. The sweet taste shows that the starch has changed into sugar for the nourishment of the growing plants.

(*g*) Cut off a stem of geranium and apply the moist surface to a bit of blue litmus-paper. The latter will turn red on account of the presence of an acid in the water of the cells.

171. **Temperature.**—It may readily be seen that plants are active only between certain temperatures. There is for every plant a certain highest temperature (maximum) beyond which there is no activity. Likewise there is also a lowest temperature (minimum) below which activity ceases. Between these there is a best temperature (optimum) at which the plant is most active. We have thus three temperatures which should be studied for each plant, viz., lowest, best, highest, or, as they are commonly referred to in botanical works, the minimum, optimum, and maximum.

172. The lowest temperature for plants ranges from near the freezing point of water to 10 or 15 degrees Cent. above it (32° to 50° or 60° Fahr.). It is not the same for different plants, some being active at much lower temperatures than others. Moreover, in each plant, the lowest temperature varies for the different parts; thus roots are active at much lower temperatures than leaves. As a rule, also, metastasis can take place at lower temperatures than assimilation.

173. The highest temperature for plant-activity ranges from about 35° to 50° Cent. (95° to 122° Fahr.), varying somewhat for different plants, and varying also for different parts or different functions of the same plant.

174. The best temperature varies still more than the

lowest or the highest. There are plants whose whole lives are passed in temperatures but little above the freezing point of water, the Red-snow plant being a good example. Many seaweeds flourish in waters which never rise above 5° to 10° Cent. (40° to 50° Fahr.), while others grow only where the temperature is 20° to 30° Cent. (about 70° to 85° Fahr.).

175. For ordinary land-plants the best temperature varies for the different parts and functions somewhat as in case of the lowest and highest. The best temperature for roots is generally somewhat lower than that for the parts above the ground, and likewise for the production of fruit and seeds it is higher than that for the simple growth of leaves and stems.

176. The minimum, optimum, and maximum temperatures for the germination of the seeds of some common plants have been determined to be about as follows:

	Minimum.	Optimum.	Maximum.
Indian Corn.	9° C. (= 48° F.)	34° (C. = 92° F.)	46° C. (= 115° F.)
Scarlet Bean.	9° C. (= 48° F.)	34° (C. = 92° F.)	46° C. (= 115° F.)
Pumpkin ...	14° C. (= 56° F.)	34° (C. = 92° F.)	46° C. (= 115° F.)
Wheat......	5° C. (= 41° F.)	29° (C. = 83° F.)	42° C. (= 108° F.)
Barley......	5° C. (= 41° F.)	29° (C. = 83° F.)	37° C. (= 99° F.)

177. When the temperature rises above a certain point the death of the plant takes place. Those plants, or parts of plants, which contain the least water are capable of enduring higher temperatures than those which are more watery. The immediate cause of death appears to be the coagulation of the albuminoids of the protoplasm. The protoplasm thus loses its power of imbibing water, and the cells consequently lose their turgidity. In watery

tissues chemical changes at once begin, resulting in the rapid disintegration and decay of the substances in the cells.

178. In many respects the results of too great a reduction of temperature are similar to those produced by too great an elevation. There is observed the same coagulation of the albuminoids, resulting in the destruction of the power of the protoplasm to imbibe water, and, as a consequence, in the loss of the turgidity of the cells. Moreover, as in the case of injury from high temperature, those cells which are the most watery are the ones which, other things being equal, are injured most quickly by a reduction of temperature.

179. Embryo plants in seeds, when dry, are able to endure almost any degree of low temperature; but after they have germinated, and the cells have become watery, they are generally killed by a reduction to, or a few degrees below, 0° Cent. (32° Fahr.). So, too, the comparatively dry tissues of the winter buds and ripened stems of the native trees and shrubs in cold countries are rarely injured even in the severest winters, while the young leaves and shoots in the spring are often killed by slight frosts.

180. Death from low temperature is always accompanied by the formation of ice-crystals in the succulent tissues; these are formed from the water of the plant, which is abstracted from it in the process of congelation. Much of the water thus frozen is that which fills the cavities (vacuoles) of the cells, while some of it is that which moistens the protoplasm and cell-walls.

181. As the liquid in the vacuoles is not pure water, but a mixture of several solutions, it freezes at a lower temperature than water, and then, according to a well-known

law of physics, separates into pure ice-crystals and a denser unfrozen solution. By a greater reduction of temperature more ice-crystals may be separated out, and the remaining solution made denser still. This increasing density tends to retard the formation of ice-crystals, and it is probable that it is only in extremely low temperatures, if at all, that the liquids in the plant are completely solidified.

182. A plant which has been frozen may survive in many instances if thawed slowly, but if thawed quickly its vitality is generally destroyed. Thus many herbaceous plants will endure quite severe freezing if they are afterward covered so as to secure a slow rise of the temperature, and many bulbs, tubers, and roots will survive the severest winters if covered deeply enough to prevent sudden thawing. Likewise turgid tissues, which are not living, as those of many succulent fruits, are injured or not by freezing, according as the thawing has been rapid or slow.

183. **Light.**—All green plants are directly dependent upon light, for it is only in the light that they can manufacture starch. Without light they would starve just as surely as would animals if deprived of their proper food.

184. Light does not appear to be essential to plants in any other way than to enable them to make starch; so that those which get their starch from others can live in total darkness. Thus many saprophytes (i.e., plants which live upon dead or decaying vegetable matter) are found in dark cellars, caves, mines, etc., growing to full size and maturing their fruit perfectly. So, too, some parasites (i.e., plants living upon and getting their food from living plants) grow in darkness, feeding upon the inner tissues of their hosts (supporting plants) where little or no light penetrates.

185. The flowers and fruits of ordinary plants develop

as well in darkness as in the light, behaving in this respect like parasites and saprophytes.

Practical Studies.—(*a*) Plant a few seeds of radish, barley, wheat, and Indian corn in each of two flower-pots, and place one of the pots in a cool cellar and the other in a warm room. Note differences in growth in the plants in each pot, and also compare growth of similar plants in the two pots.

(*b*) Observe the average daily temperature during the time that the hickory-trees are opening their buds in the spring. Compare this with the average temperature during the time of most vigorous development of the leaves and twigs, and also during the time of the development of the fruit.

(*c*) With a thermometer measure the temperature of the water of ponds and ditches when the earliest vegetation appears in the spring. This consists for the most part of diatoms which form a brownish scum on the water, or a brown coat on sticks and stones.

(*d*) Measure in like manner the temperature of cold springs in which vegetation is found.

(*e*) When Indian corn is producing its flowers (tassels and silk), observe the average temperature of the air and compare it with the temperature of the soil at the average depth of the roots.

(*f*) Enclose a small plant of Coleus (a common "foliage-plant") and a clover-plant in a tin pail, covering them loosely. Enclose also a thermometer. Set the pail in a tub of ice-water, allowing it to remain for an hour or two. Note the effect upon each plant. Or make the experiment by first growing little plants of wheat and pumpkin or squash, and using these. The wheat will survive; the pumpkin or squash will not.

Now make an experiment substituting hot water, and using a spring plant (as hepatica or anemone) and a summer plant (as Indian corn). Raise the temperature to 40° Cent. (104 Fahr.), and then increase the heat very slowly beyond this point. Notice effect upon each plant.

(*g*) In the autumn notice that some plants are killed by frosts which leave others unharmed.

(*h*) Thaw out two frozen apples, one in warm water rapidly, and the other in ice-water slowly. The first will be more injured, the second less.

(*i*) Look for moulds and other fungi in dark cellars, as examples of saprophytic plants which have grown without the direct aid of light.

(*j*) Cover the end (30 to 40 centimetres) of a cucumber-plant, bearing young flower-buds, with a tight box so as to exclude all light. Notice that the flowers develop perfectly as to size and color, although in total darkness, while the leaves are small and lacking in normal color.

(*k*) Cover in like manner a portion of a cucumber-plant bearing very young fruit. Notice that the fruit develops in darkness as well (in size at least) as in the light.

186. **Movements of Plants.**—Every living plant is capable of moving. In some cases the movement is so small that it is not visible to the naked eye, while in others it is very evident. It is popularly supposed that animals alone have the power of movement, and that this power is one of the prominent distinctions between plants and animals. In fact, however, no plant is wanting in the power of movement, and there are many plants which are much more active than certain animals.

Only an outline of this interesting subject can be given in this place, and the student who wishes to pursue the subject further should consult Mr. Darwin's book, "The Power of Movement in Plants," published in 1881.

187. Mr. Darwin has shown by a great number of observations that as soon as a seed germinates every part of the embryo begins moving in various directions. Thus the little root at once begins a sort of revolving motion, its tip describing more or less curved figures. This revolving or bending in succession towards all points of a curved figure so as to describe an ellipse or circle is called circumnutation, an inconveniently long word for what is, as we shall see, a very common thing in plants.

188. By the circumnutation of a root it is enabled to find those places in the soil which offer the least resistance to its passage. Moreover, it has been shown that the tip

of the root is sensitive to pressure, and when it comes in contact with any object bends from it. In this way the root-tip guides the advancing root through the interstices of the soil, avoiding on every hand the pebbles and harder bits of earth. The root-tip appears, also, to be sensitive to moisture, bending towards that side which is most moist, and thus in a dry soil the roots are constantly guided into those parts where the moisture is most favorable.

189. Not only is the root-tip endowed with the power of circumnutation, but, in the words of Mr. Darwin, "All the parts or organs in every plant whilst they continue to grow are continually circumnutating. If we look, for instance, at a great acacia-tree, we may feel assured that every one of the innumerable growing shoots is constantly describing small ellipses; as is each petiole, sub-petiole, and leaflet. The flower-peduncles are likewise continually circumnutating; and if we could look beneath the ground and our eyes had the power of a microscope, we should see the tip of each rootlet endeavoring to sweep small ellipses or circles, as far as the pressure of the surrounding earth permitted. All this astonishing amount of movement has been going on year after year since the time when, as a seedling, the tree first emerged from the ground."

190. This general power of movement is subject to modification by various agencies. Thus we find that in most plants the change from daylight to the darkness of night is accompanied by changes of position in many parts, the nocturnal position being called the sleep of the plant. So, too, the influence of direct light produces a bending or turning of certain parts of plants toward the light, a kind of movement which has been called heliotropism. Gravitation has, also, been found to produce a special modifica-

tion of movement, known as geotropism; and, lastly, we may regard the irritableness of certain plants, as, for example, the sensitive-plant, as a high specialization of the general power of movement possessed at some time or other by all plants and all parts of plants.

191. In regard to the sleep of plants, observation has shown that at night the cotyledons (first leaves of the seedling) of many plants take a different position from that which they have during the day. In the cabbage and radish, for example, the cotyledons stand during the day almost at right angles to the stem, but at night they rise and are parallel to one another. Seedlings of parsley, celery, tomato, and four-o'clock behave in a similar manner. In some cases the cotyledons instead of rising, at night, bend abruptly downwards. This happens with seedlings of certain kinds of sorrel (Oxalis), although curiously in other species of the same genus the cotyledons rise.

192. The leaves of many (if not all) plants assume a position at night more or less different from that which they have during the day. In the common purslane the leaves at night bend upwards in such a manner as to lie more nearly parallel with the stem. In wood-sorrel (Oxalis) the leaflets bend abruptly downward and closely surround the common leaf-stalk. In clover, on the contrary, the leaflets bend upwards, afterwards folding over to one side. In beans the leaflets sink down somewhat after the manner of the wood-sorrel. In some cassias and the sensitive-plants the nocturnal position differs remarkably from that of the day; not only are the leaflets folded, but the leaf-stalks change their position, in some cases rising and in others becoming sharply depressed. Even some conifers have been observed to show a well-marked sleeping state at night.

193. The relatives of the beans (i.e., the leguminous plants, or Leguminosæ) have been most frequently observed in a sleeping state; but it is very likely that when we study them attentively very few of the higher plants will be found which are wanting in this power.

194. The familiar closing of certain flowers at night and opening again in the morning, and the exactly reversed action, are to be regarded as of the same nature as the diurnal and nocturnal position of leaves.

195. The turning of leaves and stems toward the light, as is commonly seen in a plant grown in a window, is regarded by Mr. Darwin as a modified circumnutation. Here the lateral light controls ordinary nutation, and modifies it so that, instead of describing ellipses, the leaf or stem moves in a zigzag course toward the light. The stronger the light the more nearly will the course approach to a straight line. Some plants or parts of plants when exposed in this way to the light bend away from it: this is well seen in the runners of the so-called strawberry-geranium (Saxifraga sarmentosa), a well-known pretty little basket-plant. This last kind of bending is known as negative heliotropism, while the bending toward the light is distinguished as positive heliotropism.

196. Allied to the foregoing is the bending of roots and stems toward or away from the earth, i.e., with or in opposition to the force of gravitation. It is a familiar fact that in the growth of most seedlings the roots grow downward while the stems take an upward direction. Experiments made long ago proved that this was due in some way to the action of gravitation, and Mr. Darwin now considers it to be the result of gravitation acting upon and modifying the circumnutation of root and stem. Geotropism (as this

is called) and heliotropism have then this in common, that both have as their basis that continual movement of the plant which appears to be the constant accompaniment of life; in the one case this movement receives special direction and impulse from the light, while in the other the impulse is given by the force of gravitation.

197. We may now also connect the movements due to ordinary mechanical stimuli with the foregoing. In the well-known sensitive-plant a slight touch or jar is sufficient to cause the leaves to close with considerable rapidity. This was for a long time referred to an obscure irritability, which was regarded as something peculiar to a few plants. If, however, we bear in mind that motion appears to be the normal state of growing parts, or parts whose tissues remain thin-walled, we see that this "irritability" is not a peculiarity at all, but only an intensification of that which is possessed by plants in general.

Practical Studies.—(*a*) Soak a few beans in water, and when the little roots begin to protrude pin the beans carefully to a weighted cork under a bell jar, and observe the movements of the radicles.

(*b*) Germinate and study in like manner the seeds of cabbage, radish, Indian corn.

(*c*) Fix a slender filament of glass to the rapidly growing end of a shoot of fuchsia, geranium, or verbena (using a drop of thick shellac-glue), and observe the circumnutation. If a plate of glass be laid horizontally just above the tip of the glass pointer, the movements of the latter may be readily recorded by lines or dots on the glass. Or a microscope may be fixed in such a position that the tip of the pointer is in focus, when the movement will be made visible to the eye.

(*d*) Fix a glass pointer to the tip of a leaf of a suitable plant (as a fuchsia, geranium, primrose, etc., grown in a pot), and record the nutations on a glass plate fixed vertically or horizontally in such a way as to be approximately at right angles to the pointer.

(*e*) Germinate seeds of cabbage, radish, parsley, or tomato, and note carefully the position of the cotyledons during the day and night.

(*f*) Observe the sleeping state of wood-sorrel (Oxalis), clover, and purslane. Then make careful notes of diurnal and nocturnal positions of the leaves of as many plants as possible. Where it is possible to do so, it is recommended that photographs be taken of the waking and sleeping states of plants. Careful sketches, at least, should be made.

(*g*) Select a symmetrically grown fuchsia, place it in a window, and note the rapidity with which the leaves and stems turn toward the light.

(*h*) Germinate various seeds in a window, and observe the heliotropism of the seedlings.

(*i*) Grow a strawberry-geranium (Saxifraga sarmentosa) in a hanging basket or pot in a window, and observe that the dependent runners bend away from the light.

(*j*) Germinate beans, and after the radicles have protruded a centimetre or two fasten the seeds in such a way (under a bell-jar) that the radicles point directly upwards. Observe that the roots soon begin bending towards the earth.

(*k*) Grow a few sensitive-plants in pots for study of irritability. Seeds may be procured at any seed-store for a few cents, and are easily grown in a warm room.

CHAPTER VI.

CLASSIFICATION AND DISTRIBUTION.

198. We may now proceed to take a hasty survey of the vegetable kingdom, studying here and there a selected example which must serve to illustrate the structure of a considerable group. In such a study of plants it is better to begin with the simpler and more easily understood forms, and to pass from these to those which are structurally more complex and whose functions are correspondingly complicated.

199. On account of the vast number of species of plants (probably exceeding 150,000) it is necessary for us to group them in such a way as to bring together those which resemble one another. In such grouping we take into consideration as many things as possible, and those plants which are alike or similar in the greatest number of particulars are considered to be more nearly related to each other than those with fewer points of resemblance. Moreover, it has been found that resemblances in structure are of far greater importance than resemblances in habits. Two plants, for example, may be parasitic in habit, and yet their structural differences may be so great as to warrant us in placing them in entirely different groups of the vegetable kingdom.

200. If we bring together all the plants of the vegetable kingdom, we may recognize pretty easily six or seven large groups, all the members of which show more or less of re-

semblance to each other. These are called Branches, or Divisions. Likewise, if we consider the plants in each Branch, we may make several groups, each of which will include those with still greater resemblances. These groups are called Classes.

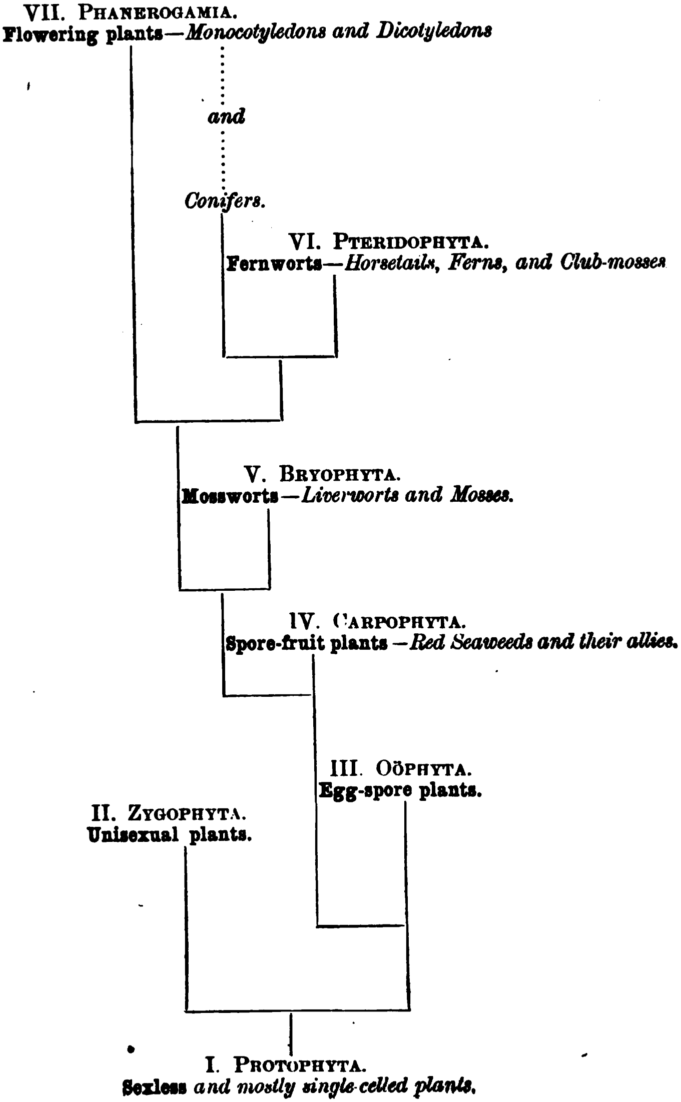
201. In like manner Classes are divisible into Orders; Orders into Families; Families into Genera; Genera into Species. Each Species is composed of individual plants, all of which bear a close resemblance to each other. In some Species there is such a variation in the individuals composing it that they are grouped into Varieties.

202. Applying the foregoing, we have the following as the classification of the common Sunflower:

- Kingdom of Vegetables.
  - Branch, Phanerogamia.
    - Class, Angiospermæ.
      - Order, Compositæ.
        - Genus, Helianthus.
          - Species, annuus

203. There are needed now and then various sub-groups; thus Classes are often separated into two or more Sub-Classes, and these again into Series and Cohorts; so Orders are sometimes separated into Sub-Orders, or they are more frequently divided into Tribes and these again into Sub-Tribes. So, too, a Genus may be divided into Sub-Genera. On the other hand, it is very common for Family to be omitted, as in the case of the Sunflower given above.

204. The general relationship of the Branches of the Vegetable Kingdom is sometimes shown by constructing a tree or diagram, whose principal divisions represent the Branches. Such diagrams (as the one on the opposite page) are often quite helpful to the student.


VII. Phanerogamia.
Flowering plants—Monocotyledons and Dicotyledons
and
Conifers.
VI. Pteridophyta.
Fernworts—Horsetails, Ferns, and Club-mosses
V. Bryophyta.
Mossworts—Liverworts and Mosses.
IV. Carpophyta.
Spore-fruit plants—Red Seaweeds and their allies.
III. Oöphyta.
Egg-spore plants.
II. Zygophyta.
Unisexual plants.
I. Protophyta.
Sexless and mostly single-celled plants.

205. Plants are distributed widely over the surface of the earth. They are most abundant in the hotter climates, and decrease in number toward the poles. Likewise, they are more abundant upon the lowlands than upon the tops of high mountains. The regularity and amount of rainfall has also a controlling influence upon land-vegetation, while for marine forms the direction and temperature of the ocean-currents largely determine their distribution.

206. In general, we may say that light, temperature, and moisture are the chief controlling agents. Where these are favorable, there vegetation is abundant; where they are unfavorable, vegetation is scanty or wanting. The cold and poorly lighted polar regions (VI and VI′ of the map), the cold mountain-summits, the dry deserts of Africa and Australia (IX and IX′), and the dark depths of the oceans, are alike deficient in vegetation.

207. In general, similar conditions have brought about similar vegetations. The North American Forest Region (I) of the Western Hemisphere has its counterpart in the Europæo-Siberian Forest Region (I′) of the east, in which approximately similar conditions prevail. So, too, the Prairie Region of North America (II) is to be compared with the Steppe Region of Asia (II′), the Pampas Region of South America (II″), and the South African Region (II‴). The Californian Region (IV) is in many respects similar to the Mediterranean Region (IV′) and the Chili-Andean Region of South America (IV″).

208. The accompanying map (Fig. 42) shows one of the ways of dividing the earth into botanical regions. Each region is capable of subdivision into *districts.* The plants of a region or district constitute a *flora;* thus we may speak of the Prairie Flora, or the flora of the Upper Mississippi district, or the flora of Iowa,

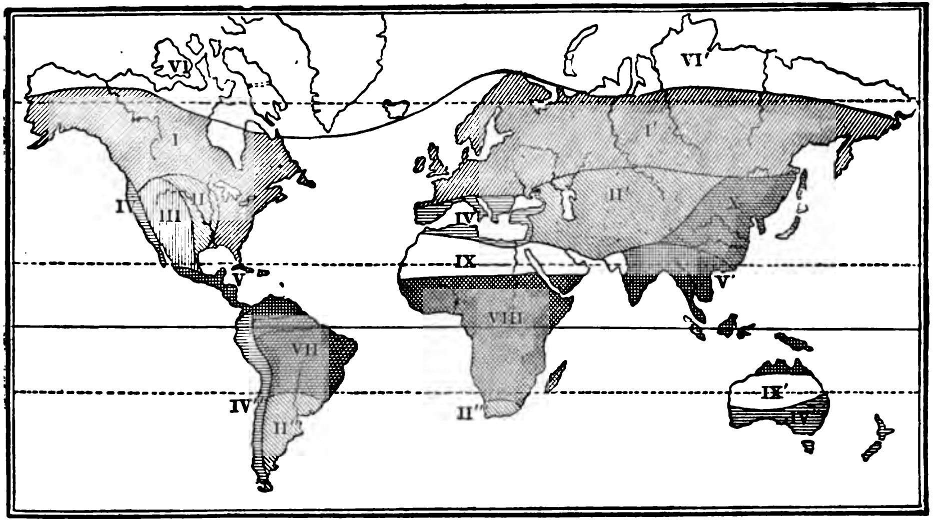


FIG. 42.—I, North American Forest Region. I', Europæo-Siberian Forest Region. II, Prairie Region. II', Steppe Region. II'', Pampas Region. II''', South African Region. III, Rocky Mountain Region. IV, Californian Region. IV', Mediterranean Region. IV'', Chili-Andean Region. V, Central American or West Indian Region. V', East Indian Region. VI, Arctic Region. VII, Brazilian Region. VIII, Central African Region. IX, Sahara Region. IX', Australian Desert Region. X, Chino-Japanese Region.

209. Most plants are short-lived. By far the greater number perish in a year or two, as is the case with our annuals and biennials. Some shrubs and trees may live for a considerable number of years, but even the most enduring generally die in a few centuries. The plants of the world are thus constantly dying off, and are as constantly being renewed. Occasionally the dying off in a particular species was more rapid than the renewal, in which case the species eventually became extinct: many such cases are known to palæontologists. On the other hand, it has frequently happened that new forms have appeared as the older ones have died off, so that the character of a particular flora has thereby been gradually changed.

210. By a study of the fossil plants of any period in the world's history we may learn that the flora of each region has undergone great changes. The flora of North America in the Tertiary period was very different from what it is now, while the Cretaceous flora was still more unlike that of the present. Plants that now are confined to the eastern continent were then common in many parts of this continent, and tropical or sub-tropical species flourished abundantly in Nebraska and Dakota.

211. Moreover, we learn by such a study that many of the plants of the present were not yet in existence in certain geological periods. As we go back in geological time the vegetation is less and less like that of to-day. Thus, the higher flowering plants (Dicotyledons) were not in existence earlier than the Cretaceous period, while the Lilies and their relatives date back to the Triassic. The great Carboniferous vegetation, from which our coal was derived, contained no plants with true flowers. There were no grasses or sedges, no lilies or orchids, no roses or violets, no

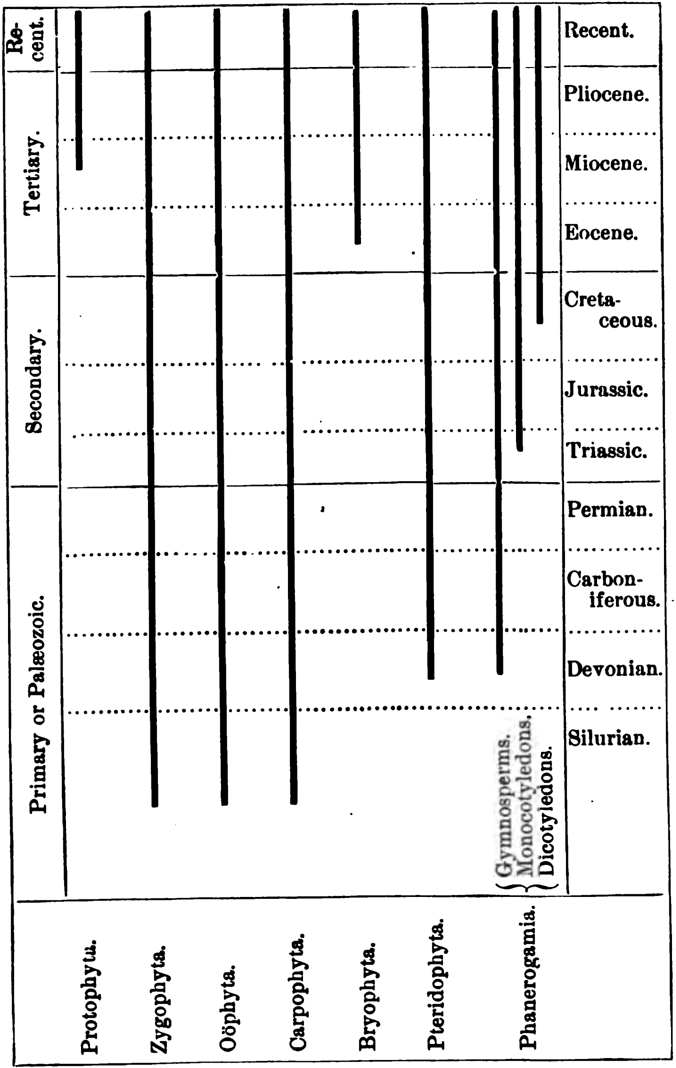


FIG. 43.—Chart showing distribution of plants in Geological Time.

oaks or maples. There were cone-bearing trees and tree-ferns, as well as gigantic club-mosses and horsetails; but even these were very different from any now living.

212. The foregoing table (Fig. 43) will show the main facts as to the distribution of the principal branches of the vegetable kingdom in geological time. It must be remembered that the geological record is as yet only fragmentary, and in all probability many of the lines will be carried down much further as our knowledge becomes more complete.

CHAPTER VII.

BRANCH I. PROTOPHYTA.

THE SEXLESS PLANTS.

213. The protophytes are the lowest and simplest plants, and they are often so minute as to require the highest powers of the microscope for their study. For the most part the cells are poorly developed; the protoplasm is frequently destitute of granular contents; the nucleus is wanting in many cases; and not infrequently there is either no cell-wall or only a poorly developed one.

214. The cells in all cases cohere little, if at all; and even when they are united into loose masses each cell retains nearly as much independence as in the single-celled forms.

215. No sexual organs are known. The common mode of reproduction is by the fission of cells, although internal cell-division occurs also.

216. Most protophytes live in water and get their food from the solutions it contains. Some are green or greenish, and so are able to use carbon dioxide, while others are destitute of a green color and are parasites or saprophytes.

217. Three classes of protophytes may be distinguished, as follows:

1. Naked shapeless protoplasm—Slime-moulds (*Myxomycetes*).
2. Minute cells, not green—Bacteria and Yeast (*Schizomycetes*).
3. Cells green, or greenish—Green Slimes (*Cyanophyceæ*).

CLASS I. SLIME-MOULDS (*Myxomycetes*).

218. The Slime-moulds are in many respects the most remarkable of all known plants. They bear so strong a resemblance to the lowest animals (Protozoa) that they have been, time and again, placed in the animal kingdom by various naturalists. When we compare them with any other plants, they are found to differ from them so widely that very little relationship can be detected.

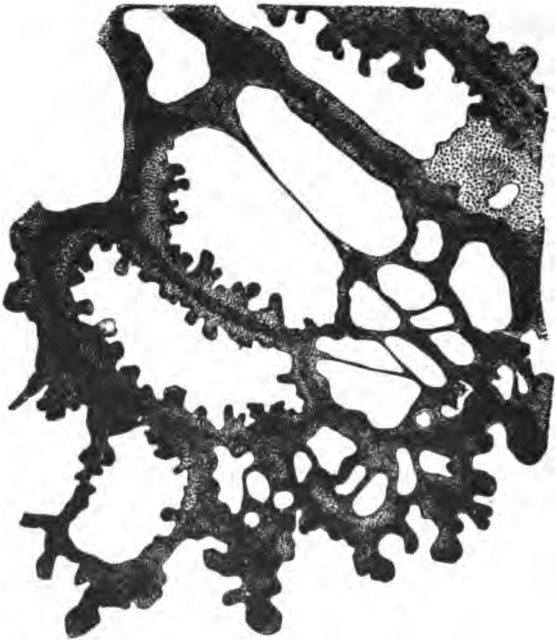


FIG. 44.—A part of a Slime-mould (Physarum leucopus) in its vegetative stage. Magnified 350 times.

219. A Slime-mould is a mass of naked, shapeless protoplasm (Fig. 44) during all the growing part of its life. In

some species it is no larger than a pin-head, while in others it is as large as a man's hand. This mass of protoplasm is often yellow or orange-red in color, and is never green. It possesses to an extraordinary degree the power of moving itself from place to place. Slime-moulds obtain their food by absorbing solutions of decaying matter, and are even said to engulf solid substances in the same manner as the Amœba among animals.

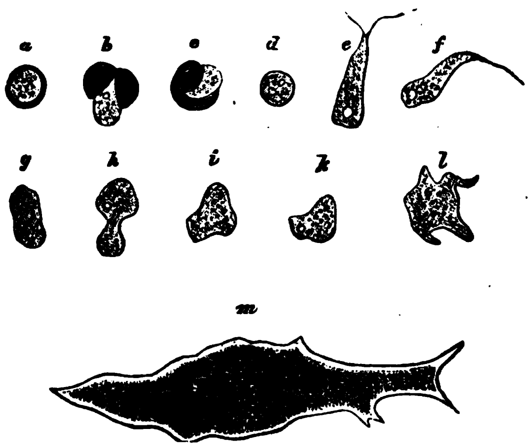


FIG. 45.—Early stages of a Slime-mould (Fuligo varians). *a*, a spore; *b*, *c*, the same, bursting the cell-wall; *d* to *l*, various stages; *m*, young Slime-mould.

220. When they have become full-grown they lose a good deal of their moisture, and the protoplasm then separates itself into a great number of minute rounded balls, each of which forms a cell-wall around itself. These little balls (spores) are thus nothing but bits of protoplasm securely covered. They may now be blown hither and thither without harm, and when at last they fall into a moist warm place they imbibe water, burst their coats, and are free

naked masses of protoplasm again, thus completing the round of life (Fig. 45).

There are seven orders of Slime-moulds, which are distinguished mainly by their structure in the spore-bearing stage. Many species occur in all parts of the United States, and may be readily found on decaying logs, stumps, etc., and on the bark-covered ground in tanyards. A fine large one—Fuligo varians—is especially common in the last-named situation.

CLASS II. BACTERIA AND YEAST-PLANTS (*Schizomycetes*).

221. The plants of this class are minute cells, each consisting of a mass of protoplasm surrounded by a thin wall. The cells cohere but little, and in some cases not at all. They contain no chlorophyll, and always live in solutions of nourishing matter. Two orders are generally recognized, the one containing the Bacteria, and the second the Yeast-plants.

222. **Bacteria.**—These are the smallest of living things. Their minute cells in some cases measure no more than .0005 mm. ($\frac{1}{50000}$ inch) in diameter. They are in some species rounded in shape, in others elongated like little rods, or in others more or less curved (Fig. 46). They are frequently provided with one or two cilia (i.e., whip-like projections of protoplasm), by means of which they move about with great activity.

223. Bacteria are found in great numbers in the watery parts of decaying organic matter, causing various kinds of fermentation. They reproduce by fission with such astonishing rapidity that in a short time they swarm in any exposed substance which is capable of furnishing them with food. Some of the species live in the watery juices of plants and animals, causing various diseases.

224. Some bacteria can endure high temperatures, and

frequently appear in tightly closed vessels whose contents have been boiled. Some people have been led to explain their appearance under such circumstances by "spontaneous generation;" but thus far the facts are capable of other explanation.

225. On account of their minuteness, bacteria may be picked up by currents of air and borne long distances, and in this way they are doubtless often carried from place to place. When a pool of putrid water dries up, the bacteria with which it swarmed are blown away with the dust and dirt, dropping everywhere into pools, upon plants and animals living and dead, and even entering our lungs with the air we breathe.

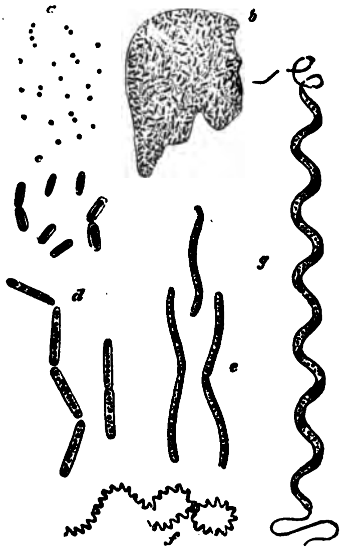


FIG. 46.—Forms of Bacteria. *a*, Micrococcus prodigiosus; *b*, Bacterium termo (resting stage); *c*, Bacterium lineola; *d*, Bacillus ulna; *e*, Spirillum rugula; *f*, Spirochæte plicatilis; *g*, Spirillum volutans. Magnified 650 times.

Among the bacteria which are of especial interest to us are the following:

1. The bacterium of small-pox (Micrococcus vaccinæ), composed of minute globular cells, is now accepted as the cause of small-pox. That found in vaccine virus is a cultivated state, while that in small-pox is its virulent state.

2. The bacterium of diphtheria (Micrococcus diphtheriticus), similar to but smaller than the preceding, is present in the body when suffering from diphtheria.

3. The bacterium of ordinary putrefaction (Bacterium termo, Fig. 46, *b*) is composed of oblong cells. It is the cause or accompaniment of all ordinary decay of animal and vegetable substances.

4 The bacterium of anthrax or splenic fever (Bacillus anthracis) is composed of cylindrical cells, which are motionless. It occurs in the blood of animals suffering from the diseases named.

5. The bacterium of consumption (Bacillus tuberculosis), of very slender cylindrical, motionless cells, has recently been shown to occur in the lungs and air-passages of consumptive patients.

6. The bacterium of leprosy (Bacillus lepræ), of cells similar to the preceding but larger, is found in the tissues of those afflicted with leprosy.

Practical Studies.—(*a*) Put a pinch of cut hay or any other similar vegetable substance into a glass of water; keep in a warm room for a couple of days, or until it becomes turbid (from the abundance of bacteria); examine a minute drop with the highest powers of the microscope for active bacteria.

(*b*) Put a bit of fresh meat into water, and study the bacteria which will appear in it. Spiral forms like *g*, Fig. 46, may often be found in such a preparation.

(*c*) Examine the juices of decaying fruits.

226. **Yeast-Plants.**—If a bit of yeast be placed upon a glass slip and carefully examined under high powers of the microscope, there will be seen a great many small roundish or oval cells, of a pale or whitish color. They have a cell-wall, but generally the nucleus is wanting or indistinct. These little cells are Yeast-plants, and bear the name of Saccharomyces cerevisiæ.

227. They reproduce by a kind of fission, called budding. Each cell pushes out a little projection which grows larger

and larger, and finally a cell-wall forms between the two, which sooner or later separate from one another (*a* and *b*, Fig. 47). Under certain circumstances new plants form internally, as in *c* and *d*, Fig. 47.

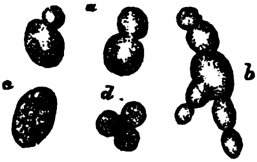


FIG. 47.—Yeast-plants in various stages of growth, *a* and *b*. At *c* and *d* new cells have formed by internal cell-formation. *a* and *b* magnified 400, *c* and *d* magnified 750 times.

228. Yeast-plants are saprophytes, and live upon the starch of flour. They break up the starch, and in the process liberate considerable quantities of carbon dioxide, which appears as bubbles upon the surface of the yeast. Another result of the breaking up of the starch is the formation of alcohol; hence the growth of yeast-plants in a starchy substance is always accompanied by what is known as alcoholic fermentation. The housewife and baker use yeast-plants for the carbon-dioxide gas which they evolve, to give lightness to the bread, while the brewer and distiller use the same plants for the alcohol produced by their activity.

Practical Studies.—(*a*) Fill a strong bottle half full of active yeast, cork tightly, and keep for an hour or two in a warm room. Draw the cork and notice the violent escape of gas (carbon dioxide).

(*b*) Place a small drop of the yeast upon a glass slide, add a little water, cover with a cover-glass, tapping it down gently. After a little examination under a high power of the microscope, add iodine, which will stain the starch-grains blue or purple, and the yeast-plants yellowish. Many of the latter will be found in process of budding, as in *a* and *b*, Fig. 47.

(*c*) Spread a half-teaspoonful of yeast on a fresh-cut slice of potato or carrot; cover with a tumbler or bell-jar to keep it moist; after a few days (4 to 8) examine for cells which are reproducing by internal cell-formation, as in *c* and *d*, Fig. 47.

CLASS III. GREEN SLIMES (*Cyanophyceæ*).

229. These are single cells, or chains of cells, usually of a blue-green or brownish-green color, and generally inhabiting the water. They very commonly form slimy masses or films on the water, or the moist surfaces where they grow. In their decay they emit a putrid odor, and when abundant, as they sometimes are in city water-supplies, are quite troublesome and offensive.

230. The lower Green Slimes are single-celled, as in Chroöcoccus, Glœocapsa (Fig. 48), and other genera. Each cell divides into two, and these soon divide again, and so on. In Glœocapsa the cell-wall is much swollen into a jelly-like mass.

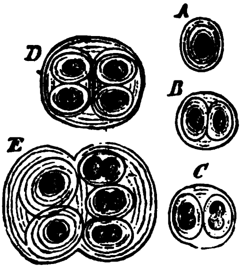


FIG. 48.

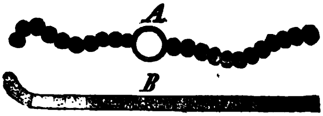


FIG. 49.

FIG. 48.—Cells of Glœocapsa in different stages of growth, showing division and the mode in which the daughter-cells are surrounded and enclosed by the gelatinous walls of the mother-cells. *A*, youngest; *E*, oldest stage. Magnified 300 times.

FIG. 49.—*A*, filament of Nostoc; *B*, end of filament of Oscillaria. Magnified 300 times.

231. In the Nostocs and their near relatives (Oscillaria) there is a little coherence of the cells into chains or filaments. The cells form by fission, but after formation adhere somewhat to each other. The Nostocs (Fig. 49, *A*) occur in water or on moist ground as jelly-like masses of

filaments. Some are amber-colored, some brownish, some bluish-green. The species of Oscillaria (Fig. 49, *B*) are mostly dark-green filaments collected into felt-like masses floating on the surface of the water, or growing on wet earth or the wet sides of watering-troughs, etc. A peculiarity of these plants is their power of oscillating from side to side, while at the same time they move forward. In this manner they are enabled to travel considerable distances.

232. In Rivularia the filaments are generally arranged radially in little rounded masses. One of these (Rivularia fluitans) is often very abundant in lakes and slow streams, the little floating greenish balls being a millimetre or less in diameter. Other species occur as green slimy masses, as large as pin-heads, on the stones and stems of water-plants in ponds and brooks.

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233. Related to the foregoing, but probably not falling within this class, are the bright-green "Green Slimes" which have been known under the name of Protococcus. They are invariably one-celled plants, and the cells are much larger than in any of the preceding. They occur commonly on damp walls and rocks and the sides of flower-pots in greenhouses and conservatories, and in wet weather on wooden walks and the roofs and sides of houses.

234. One species of Protococcus (P. nivalis) is the noted Red-snow Plant which in the high north latitudes often covers the snow, giving it a reddish color. It also occurs on the mountain-tops in lower latitudes. Although really a green plant, its color is reddish in one of its stages.

235. In their modes of multiplication these species of

Protococcus resemble other protophytes. By fission the cells are divided into two or four new ones, and this appears to be the more common mode of increase. They also produce new cells by internal cell-formation similar to that in the yeast-plant.

Practical Studies.—(*a*) Scrape off a little of the greenish slimy matter from a damp wall, mounting it in water: examine under a high power. Some small blue-green or smoky-green cells will be found belonging to the lower Green Slimes (Chroöcoccus, etc.); of these some will probably be found in process of fission. Larger bright-green cells filled with granular protoplasm will also be found: these are a species of Protococcus.

(*b*) In midsummer look along the water-line of fresh-water lakes and ponds for soft, amber-colored, rounded masses from the size of a pea to that of a hickory-nut. By mounting a small slice of one of these, it will be seen under the microscope to be composed of myriads of filaments of Nostoc similar to *A*, Fig. 49. Occasionally a filament may be seen with a larger cell (a heterocyst), as in the figure. Its function is not known.

(*c*) Secure a handful of the dark-green filamentous growth which is common on the wet sides of watering-troughs, and place it in a dish of water. If it is an Oscillaria it will rapidly disperse itself, an hour being long enough to show quite a change in position. Now mount a few filaments in water and examine under a high power. They will be seen to sway from side to side, and to move quite rapidly across the field of the microscope.

(*d*) In midsummer scrape off one of the small jelly-like masses of Rivularia, so common on the submerged stems of water-plants, mount in water, crushing or cutting the mass so as to show the individual filaments. Each filament tapers from the centre of the mass outward, and at its larger end there is generally a larger cell (a heterocyst).

CHAPTER VIII.

BRANCH II. ZYGOPHYTA.

THE UNISEXUAL PLANTS.

236. This is an assemblage of quite diverse plants, ranging from minute unicellular species, on the one hand, to large seaweeds of considerable complexity, on the other.

237. In this branch we find the first examples of undoubted sexuality. The sexual organs all have this in common, that between the male and the female there is no appreciable difference as to form, size (with a few exceptions), color, origin, etc. The result of the union of the two sexual cells is the production of a new cell, the resting spore or zygospore, possessing very different characteristics from either. While the sexual cells have only ordinary walls, or none at all, the resting spores are covered with thick, firm walls.

238. The resting spore is so called because under certain circumstances it remains quiescent, while retaining its vitality, often for long periods of time. Thus at the close of the growing season, as upon the advent of the summer drought, or of winter, the resting spores fall to the bottom of the pools (in the fresh-water forms), and in the dried or frozen mud remain uninjured until the return of favorable conditions, when they germinate and give rise to a new generation of plants.

239. Nearly all the plants of this group contain chlorophyll, only one order being destitute of it. The green forms are all aquatic, and inhabit either fresh or salt water. Those which have no chlorophyll are mostly saprophytes, and live upon dead organic matter. They are doubtless to be regarded as modified forms of some of the types of the chlorophyll-bearing portion of the group.

240. Two classes of Unisexual plants have been distinguished, as follows:

1. Sexual cells locomotive—*Zoösporeæ.*
2. Sexual cells fixed—*Conjugatæ.*

CLASS I. ZOÖSPOREÆ.

241. In this large class the protoplasm is quite in the habit of escaping from the plant and taking on a locomotive state, in which it is called a zoöspore, a word which means an animal-like spore (from the Greek *zoön*, an animal). Under the microscope a zoöspore looks very much like a monad, and this resemblance is made still greater when we observe the cilia by which it darts rapidly through the water. All the plants of this class contain chlorophyll.

242. **Pandorina** is the pretty name given to a fresh-water plant of this class. It consists of a globular colony of green cells, each cell provided with two cilia, which project outward from the ball, and by rapid vibration give it a rotary motion (Fig. 50). At a certain stage of its development some of the cells of the colony escape and swim about in the water; finally two come in contact with one another and unite, forming a resting spore (*E*, *F*, *G*, *H*, Fig. 50). After a period of rest, the resting spore bursts its wall, the protoplasm escapes, swims about for a time by means of two cilia with which it is provided; at last it comes to rest

and divides itself into sixteen cells, which then constitute a new colony similar to that with which we started (*A*, Fig. 50).

243. **The Water-Net** (Hydrodictyon) is one of the most curious of the common plants of pools and slow streams in midsummer. Well-grown specimens are from 20 to 30 centimetres long (8–12 inches), and consist of an actual net made of cylindrical cells joined at their ends. The whole net is a colony, and the general mode of reproduction resembles that of Pandorina.

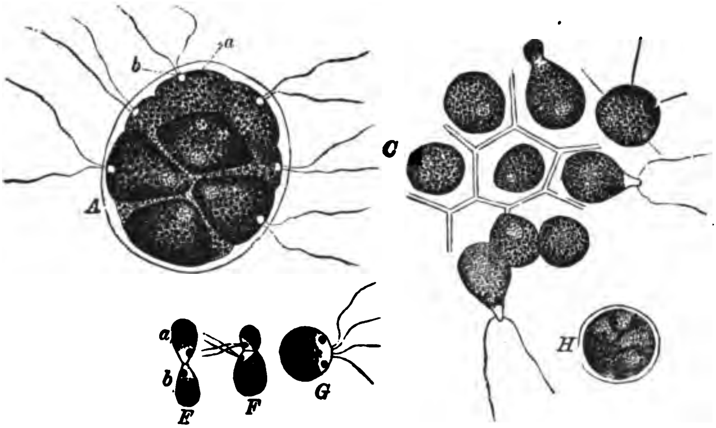

FIG. 50.—*A*, a colony of Pandorina morum; *C*, sexual cells escaping; *E*, *F*, *G*, union of sexual cells; *H*, resting spore. All highly magnified.

244. New colonies are formed also directly by the protoplasm of a cell first breaking up into a great number of small ones (by internal cell-formation), and then these soon arrange themselves into a miniature net inside of the old cell-wall. The old wall eventually decays and sets free the new colony.

245. In the common **Water-Flannel** (Cladophora) of our

creeks and rivers we have an example of a filamentous plant of the class Zoösporeæ. It is a large, dark-green, much-branched plant, which attaches itself to stones and timbers in the water. It grows so vigorously that it soon forms long matted masses, often several metres in length, which float and wave back and forth in the currents of water. It produces myriads of zoöspores.

246. **The Sea-Lettuce** (Ulva), which is common along the coast and in brackish waters, growing upon stones, wharf-timbers, etc., and resembling small lettuce-leaves, reproduces by zoöspores. The plant is composed of a couple of layers of cells, and in some of these, by internal cell-formation, zoöspores are produced; these escape into the water, where they swim about by means of their two cilia.

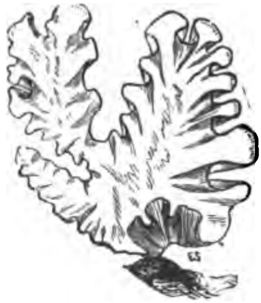

FIG. 51.—A plant of Sea-lettuce (Ulva lactuca). Natural size.

247. **Kelp and its Allies** (Phæosporeæ) make up a large group of zoöspore-bearing plants. They are all marine, often attain a great size, and are of an olive-brown color. They constitute the Kelp which is often so abundant on the seashore after a storm.

248. The large, flat, leaf-like kelp (Laminaria, commonly called Devil's Apron) may be taken to illustrate the larger forms. The "leaf" portion is sometimes from one to six metres long and nearly a metre in breadth, while its stalk sometimes attains a length of two to four metres. It is held to rocks and stones at or below low-water mark by means of root-like processes.

249. The zoöspores, which have two cilia, are produced

in certain specialized cells. These occupy particular portions of the plant-body, and compose the "fruit," so called. In Devil's Apron these fruits occur as bands or spots in the central part of the leaf. The union of zoöspores to form a resting-spore (zygospore) has been observed in but few cases, and not at all in the larger and more common species.

Practical Studies.—(*a*) In midsummer search quiet pools for water-nets. With a fine scissors cut out a piece of one and mount carefully in water. Study with a low power of the microscope. Some of the cells will be found producing zoöspores. Search for young nets forming within the old cells.

(*b*) Collect a quantity of water-flannel, and put it in a large dish of water, leaving it over night. Next morning the side of the dish which is nearest the light will show a green band at the water's edge, due to the myriads of zoöspores which escaped during the night. Mount a drop of water and search for zoöspores. Occasionally the escape of zoöspores may be seen by mounting a number of filaments and searching carefully.

(*c*) Collect sea-lettuce and study in the same way.

(*d*) Study the tissues of Devil's Apron (Laminaria) in cross and longitudinal sections.

CLASS II. CONJUGATÆ.

250. Here the sexual cells which unite are fixed; that is, they are not locomotive. The sexual act always takes place in the mature plant. No zoöspores are produced. This class includes many plants of great beauty and scientific interest. Of the four orders here noticed the first three are composed of chlorophyll-bearing plants, while in the fourth they are destitute of chlorophyll.

251. **The Desmids** (*Desmidiaceæ*) are minute unicellular fresh-water plants. The cells are of very various forms, usually more or less constricted in the middle, and divided into two symmetrical half-cells. The cell-wall is more or less firm, but never silicious.

252. The reproduction of desmids takes place by fission and by union; that is, asexually and sexually. In the first, the neck uniting the two halves of the cell elongates and becomes divided by a transverse partition, so that instead of the original symmetrical cell there are now two exceedingly unsymmetrical ones (Fig. 52); these grow by the rapid enlargement of the new and small halves; eventually the two cells become symmetrical, by which time they have separated. This process may be repeated again and again.

FIG. 52.—A desmid in process of fission. Highly magnified.

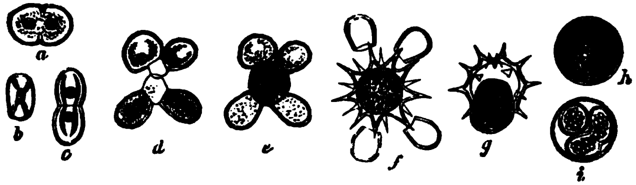

FIG. 53.—Sexual reproduction of a desmid (Cosmarium menenghinii). *a*, front; *b*, end; *c*, side view of the adult plants; *d*, two cells conjugating; *e*, young resting spore formed; *f*. ripe resting spore, with spiny wall—the four halves of the parent cells are empty; *g*, the resting spore germinating after a period of rest; *h*, the young cell escaped from resting spore; *i*, young cell dividing, showing two new plants, similar to *a*, placed crosswise in the interior of the cell. Magnified 475 times.

253. In the sexual process each of two cells which are near one another sends out from its centre a tube, which meets the corresponding one from the other (*d*, Fig. 53). At the point of meeting the two tubes swell up hemispherically, and finally, by the disappearance of the separating wall, the contents unite and form a rounded resting spore (*e*), which soon becomes coated with a thick wall (*f*). After a longer or shorter time the resting spore may germinate,

FIG. 54.—A common desmid, Closlerium. Highly magnified.

which it does by bursting its wall and dividing its contents into two parts, each of which finally becomes a new desmid (*g*, *h*, *i*).

254. **The Diatoms** (*Diatomaceæ*) are microscopic unicellular water-plants, resembling the Desmids, but differing from them in having walls which are silicified, and in the chlorophyll being hidden by the presence of a yellow coloring matter (phycoxanthine). Each cell is usually composed of two similar portions, called the valves. Each valve may be described as a disk whose edge is turned down all around, so as to stand at right angles to the remainder of the surface, making the valve have the general plan of a pill-box cover. The two valves are generally slightly different in size, so that one slips within the other (*A*, Fig. 55), thus forming a box with double sides. In other cases the valves are simply opposed and do not overlap.

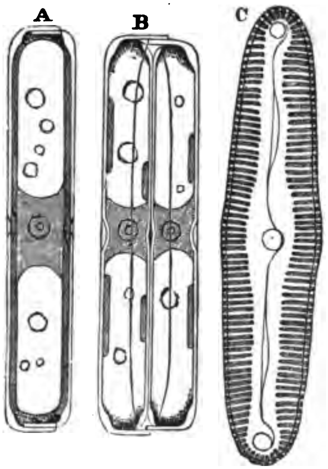

FIG. 55.—*A*, front view of a diatom, showing the overlapping walls; *B*, same view of a diatom undergoing fission; *C*, side or top view of a diatom (Navicula viridis), showing markings. Highly magnified.

255. The individuals may exist singly or in loose families; they are free, or attached to other objects by little stalks, and they are frequently imbedded in a mucous secretion. The free forms are locomotive, and may be seen in constant motion under the microscope: the mechanism of the motion is not certainly known.

256. In their reproduction diatoms resemble the desmids, the only differences being those made necessary by their rigid walls.

257. Diatoms are exceedingly abundant; they occur in both salt and fresh water, usually forming a yellowish layer at the bottom of the water, or they are attached to the submerged parts of other plants, and to sticks, stones, and other objects; they have been dredged from the ocean at great depths, and appear to exist there in enormous quantities. They are also found among mosses and other plants on moist ground. Great numbers occur as fossils, forming in many instances vast beds composed of their empty shells. The varied and frequently very beautiful markings of their valves have long made diatoms objects of much interest to the microscopist. The great regularity and the extreme fineness of the lines and points upon some have caused them to be used as microscopic tests.

258. **The Pond Scums** (*Zygnemaceæ*). The plants of this order, which are all aquatic, are elongated unbranched filaments, composed of cylindrical cells arranged in single rows. The cells are all alike, and each one appears to be independent, or nearly so, of its associates. The filament is thus, in one sense, rather a composite body than an individual. The chlorophyll is generally arranged in bands or plates.

259. The vegetative increase of the number of cells takes place by the fission of the previously formed cells. The protoplasm in a cell divides, and a plate of cellulose forms in the plane of division. This is repeated again and again, and by it the filament becomes greatly elongated. It is interesting to note that this increase of cells, which here constitutes the growth of the plant-body, is that which in

simpler plants is called the asexual mode of reproduction. In the plants under consideration there is barely enough coherence of the cells to enable them to constitute a plant-body, and one can readily see that the same fission of the cells which here increases the *size* of the plant would, if the cells cohered less, simply increase the *number of individuals.*

260. As might be expected, the filaments occasionally separate spontaneously into several parts of a considerable length, and the parts floating away give rise to new filaments. The separation takes place by the cells first rounding off slightly at the ends, so that their union is weakened at

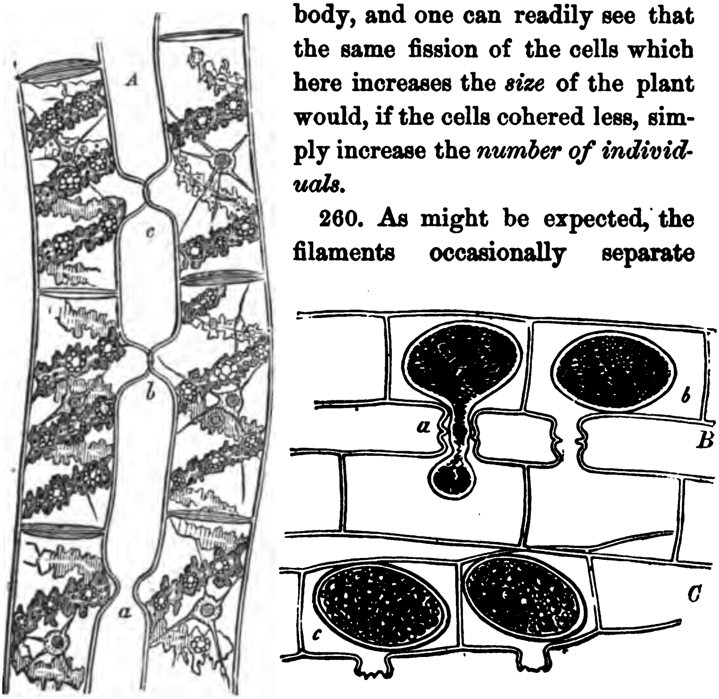

FIG. 56.—*A*, beginning of the sexual reproduction of a Pond Scum (Spirogyra longata): *a*, beginning of the formation of lateral tubes; *b*, *c*, the tubes in contact. *B*, the protoplasm passing from one cell to the other at *a*; *b*, the mass of protoplasm formed by the union of the protoplasmic contents of the two cells. *C*, two young resting spores (*c*), each with a cell-wall. They contain numerous oil-drops, and are still enclosed by the walls of the parent-cell. Magnified 550 times.

their corners; finally only the centres of the rounded ends are left in slight contact, which soon breaks.

261. The sexual reproduction is well illustrated in Spirogyra, one of the principal genera. At the close of their growth in the spring, the cells push out short tubes from their sides, which extend until they come in contact with similar tubes from parallel filaments (*A*, Fig. 56). Upon meeting, the ends of the tubes flatten upon each other, the walls fuse together and soon afterwards become absorbed, thus making a channel leading from one cell to the other (*B*, Fig. 56). Through this channel the protoplasm of one cell passes into the other, and the two unite into one mass, which becomes rounded and in a short time secretes a wall of cellulose around itself (Fig. 56, *B* and *C*). The resting spore thus formed is set free by the decay of the dead cell-walls of the old filament surrounding it; it then falls to the bottom of the water, and remains there until the proper conditions for its growth appear.

262. The germination of the resting spore is a simple process. The inner mass enlarges and bursts the outer hard coat; it then extends into a columnar or club-shaped mass, gradually enlarging upward from its point of beginning; after a while a transverse partition forms in it, and this is followed by another and another, until an extended filament is formed.

263. **The Black Moulds** (*Mucorini*) are saprophytic and some times parasitic plants; they are composed of long branching filaments (*hyphæ*), which always form a more or less felted mass, the *mycelium;* when first formed the hyphæ are continuous, but afterwards septa are formed in them at irregular intervals. The protoplasmic contents of the hyphæ are more or less granular, but they never de-

velop chlorophyll. The cell-walls are colorless, except in the fruiting hyphæ, which are usually dark-colored or smoky (fuliginous); hence the name of Black Moulds.

264. The mycelium sometimes develops exclusively in the interior of the nutrient medium; in other cases it develops partly in the medium and partly in the air. In some species the mycelium may occasionally attach itself to the hyphæ of other plants of the same order, and even to nearly related species, and derive nourishment parasitically from them. It is doubtful, however, whether any species are entirely parasitic, and so far as parasitism occurs it appears to be confined to narrow limits; none, so far as known, are parasitic upon higher plants.

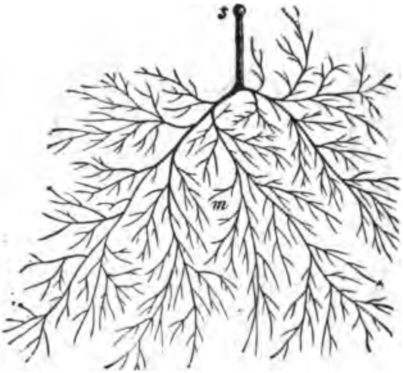

FIG. 57.—Diagram showing the mode of growth of Mucor mucedo. *m*, the mycelium; *s*, single spore-case, borne on an aerial erect hypha.

265. The reproduction of Black Moulds is asexual and sexual. In the asexual reproduction the mycelium sends up erect hyphæ (Fig. 57), which produce few or many separable reproductive cells—the spores. The method of formation of the spores in the Black Mould of decaying fruits,

pastry, etc. (Mucor mucedo), is as follows: The vertical hyphæ, which are filled with protoplasm, become enlarged at the top, and in each a transverse partition forms (*A*, *a*, Fig. 58), the portion above the partition (*b*) becomes larger, and, at the same time, the transverse partition arches up (*B*, *a*), finally appearing like an extension of the hypha, then called the *columella* (*C*, *a*). The protoplasm in the enlarged terminal cell (*b*) divides into a large number of minute masses, each of which surrounds itself with a cell-wall; these little cells are the spores, and the large mother-cell is now a spore-case, or sporangium.

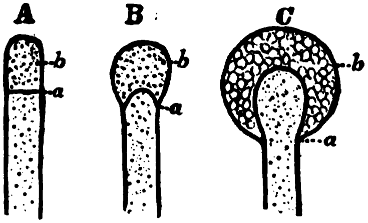

FIG. 58.—Diagrams showing mode of growth of the spore-case of Mucor mucedo. *A*, very young stage; *B*, somewhat later; *C*, spore-case with ripe spores. *a* in all the figures represents the partition-wall between the last cell of the filament and the spore-case, *b*.

266. The spores are set free in different ways: in some cases the wall of the spore-case is entirely absorbed by the time the spores are mature; in other cases only portions of the wall are absorbed, producing fissures of various kinds. The spores germinate readily when on or in a substance capable of nourishing them, by sending out one or two hyphæ, which soon branch and give rise to a mycelium. Spores may, if kept dry, retain their vitality for months.

267. Sexual reproduction takes place after the production of asexual spores. Two hyphæ, in the air or within

the nutritive medium, come near each other, and send out small branches, which come in contact with each other (*a*, Fig. 59); these elongate and become club-shaped, and at the same time they become more closely united to each other at their larger extremities (*b*); a little later a transverse partition forms in each at a little distance from their place of union (*c*); the wall separating the new terminal cells is now absorbed, and their protoplasmic contents unite into one common mass (*d*); the last stage of the process is the secretion of a thick wall around the new mass, thus forming a zygospore (*e*).

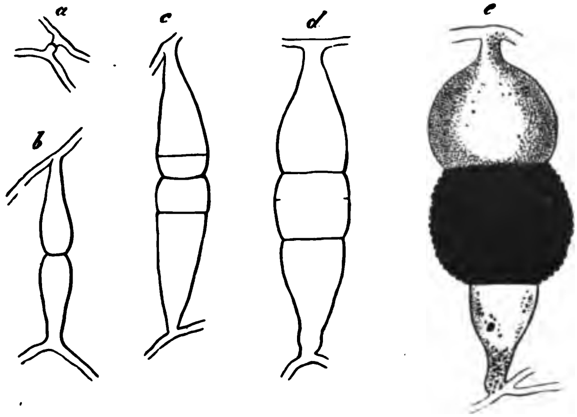

FIG. 59.—Conjugation of a Black Mould. *a*, two hyphæ near each other, and sending out short lateral tubes or branches, which come in contact; *b*, the branches grown larger; *c*, the formation of a partition near the end of each branch; *d*, absorption of the wall between the two branches, and the consequent union of the protoplasm of the end cells; *e*, resting spore fully formed. *e* magnified 90 times, the others nearly the same.

268. The resting spore does not germinate until it has undergone desiccation, and has experienced a certain period of rest, when, if placed in a moist atmosphere, it sends out hyphæ which bear spore-cases. Resting spores appear never

to form a mycelium: that s always the result of the growth of the spores from the spore-cases.

Practical Studies.—(*a*) Collect a quantity of Pond Scum and other aquatic vegetation, and preserve in a dish of water. Mount portions of this material and search for desmids, using a ¼-inch objective. Two-lobed or star-shaped desmids of a bright-green color may frequently be found. A large lunate desmid (Closlerium, Fig. 54) is often still more common. In the latter the clear protoplasm at each end is always streaming rapidly.

(*b*) Collect a little of the brownish-yellow scum which in early spring gathers on the top of the water of brooks, ditches, and pools. Mount in water and examine with a high power. Hundreds of diatoms may be seen moving rapidly across the field in every direction. In any such preparation many species of various shapes will be found. The prevailing form, however, is generally elongated and somewhat diamond-shaped.

(*c*) Study in like manner the slimy coating upon dead leaves and twigs in water in the summer for diatoms. On some of these, very fine markings may be found.

(*d*) Collect a quantity of bright-green Pond Scum which always abounds in shallow ponds and pools, and preserve in a dish of water. Collect, also, some of the same which has begun to turn yellow and brown. Upon mounting a bit of the first in water and examining with a high power, it will be found to consist of threads of cylindrical cells, each containing one or more spiral chlorophyll-bands (Spirogyra, Fig. 56) or star-shaped chlorophyll-bodies (Zygnema). Upon mounting some of the second collecting. here and there the formation of resting spores may be observed. In all cases care must be taken not to mount *too great a quantity* of the material, nor to injure the plants by rough handling.

(*e*) In the study of Black Moulds it is mostly necessary to make use of alcohol for freeing the specimens of air; afterwards they usually require to be treated with a dilute alkali, as a weak solution of ammonia or potassic hydrate, which causes the hyphæ to swell up to their original proportions.

(*f*) Cut a lemon in two, and, squeezing out most of the juice, expose the two halves to the air of an ordinary living-room or schoolroom for a few days, when various moulds will begin to develop. Under favorable circumstances Black Mould will predominate. It can be told by its dark color and the minute round black spore-cases on the ends of the erect hyphæ. Mount a few hyphæ (as directed in *e* above) and examine hyphæ, spore-cases, and spores.

(*g*) Moisten a piece of perfectly fresh bread, and then sow here and there on its surface a few spores of Black Mould; cover with a tumbler or bell-glass. In a few hours a new crop of Black Mould will begin developing.

(*h*) The most common Black Moulds are species of the genus Mucor. M mucedo and M. stolonifer are common on many decaying substances. M. syzygites occurs on decaying toadstools and other large fungi. Pilobolus crystallinus, Piptocephalis freseniana, and Chætocladium jonesii occur on animal excrement Phycomyces nitens grows on oily or greasy substances, as old bones, oil-casks, etc.

CHAPTER IX.

BRANCH III. OÖPHYTA.

THE EGG-SPORE PLANTS.

269. The distinguishing feature of the plants belonging to this division is that they develop a large cell (the oögone, or oögonium), differing from those about it in size and general appearance, which contains one or more rounded masses of protoplasm (the germ-cells), which are subsequently fertilized by the contents of a second kind of special cell of much smaller size (the antherid, or antheridium). The oögone is the female reproductive organ, and the antherid the male. The protoplasm of the latter is in some cases transferred by direct contact to the germ-cell; in other cases it first breaks up into motile bodies (the antherozoids), which then come to and unite with the germ-cell.

270. The germ-cell itself is never motile, and in most cases it remains within the parent-plant until long after it is fertilized. The result of fertilization is the production of a resting spore (here called an oöspore) which differs from the germ-cell structurally in having a hard and generally colored coating, and physiologically in having the power of germination and growth after a period of rest of greater or less duration.

271. The plants of this division vary greatly as to the development of the plant-body. In some cases it is a feebly united colony, while in its highest forms it is a well-developed thallus, with even the beginning of a differentiation into Caulome, Phyllome, and Root. Most of them are

chlorophyll-bearing, but a few are colorless saprophytes and parasites.

272. Four classes have been distinguished:

1. *Zoösporeæ*, analogous and related to the Zoösporeæ of Branch II.
2. *Œdogonieæ;* plant-body a cellular filament.
3. *Cœloblasteæ;* plant-body a tubular filament.
4. *Fucaceæ;* plant-body large and complex; color olive-green.

Class I. Zoösporeæ.

273. The little spherical Volvox of the pools and ditches may be taken as an illustration of the first class. It resembles Pandorina in many respects, and without doubt is closely related to it. Volvox is a colony of very many little cells, each of which projects its two cilia outward, giving the ball a hairy appearance. By the lashing of the cilia the ball rolls about in the water.

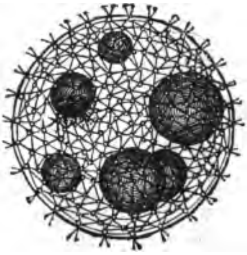

Fig. 60.—A Volvox colony, magnified about 45 times, showing young colonies within.

274. At a certain stage some of the cells enlarge and slip into the interior of the colony, becoming free oögones, each containing one germ-cell. At the same time other cells break up their protoplasm into motile antherozoids, which escape into the same cavity of the colony. At length the antherozoids unite with the germ-cell, when as a result the latter secretes a thick wall, and thus becomes a resting spore. Upon germination the resting spore divides its protoplasm into several hundred small cells, which then arrange themselves into a new colony.

275. The asexual reproduction takes place by certain cells breaking into great numbers of little cells, which then

unite themselves directly into a new colony in the interior of the parent-colony (Fig. 60).

CLASS II. ŒDOGONIEÆ.

276. The plants constituting this class are composed of articulated, simple, or branched filaments, which are attached to sticks, stones, earth, or other objects by root-like projections of the basal cells. The chlorophyll in the cells is always dense and uniform. They inhabit ponds and slow streams, and form green or brownish masses which fringe the sticks and other objects in the water.

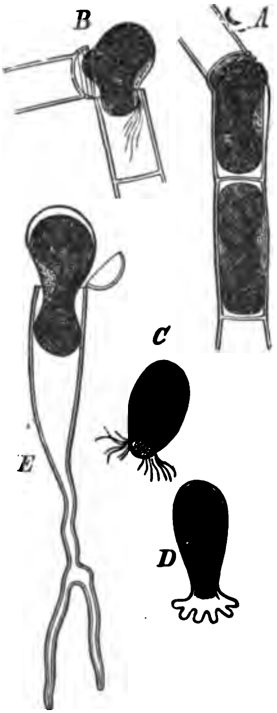

FIG. 61.—Asexual reproduction of Œdogonium. *A*, fracture of a filament; *B*, escape of protoplasm and formation of a zoöspore; *C*, swimming zoöspore; *D*, zoöspore at rest, and sending out root-like prolongations from the hyaline end; *E*, a young plant composed of only one cell, with its protoplasm escaping. Magnified 350 times.

277. The asexual reproduction of Œdogonieæ is very curious. During the early and active growth of the plants the protoplasm of certain cells escapes as a large zoöspore (Fig. 61, *A* and *B*); it is provided with a crown of cilia about its smaller hyaline end, by means of which it swims rapidly hither and thither in the water (*C*). After a time it comes to rest, clothes itself with a cell-wall, and sends out from its smaller end root-like prolongations (*D*), which attach it to some object; it now elongates, and at length

forms partitions, taking on eventually the form of the adult filament. It sometimes happens that before the new plant resulting from the growth of a zoöspore has formed its

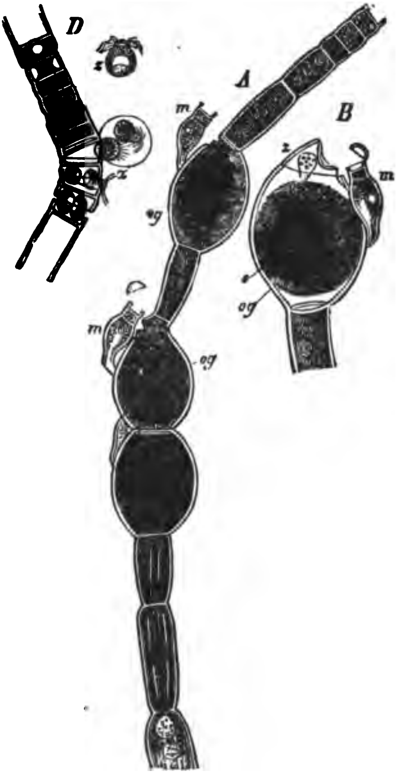

FIG. 62.—Showing the sexual state of an Œdogonium. *A*, part of a filament with three oögones. *og*; *m*, *m*, small filaments (dwarf males) which produce antherozoids in this species; *B*, an oögone at time of fertilization; *D*, part of filament of another species, showing escape of antherozoids. Highly magnified.

first partition, the protoplasm again abandons its cell, to be for a second time a zoöspore (*E*).

278. In the sexual reproduction of the plants of this class

the female organ consists of a rounded germ-cell situated within a cavity—the oögone; it is developed from one of the cells (sometimes two) of the filament by a condensing and rounding off of the protoplasmic contents; when the germ-cell is fully mature, an opening is formed in the oögone-wall for the ingress of the antherozoids (*A* and *B*, Fig. 62). One or more antherozoids are produced in certain small cells of the same or another filament; in shape they resemble the zoöspores mentioned above. Upon escaping into the water they swim about vigorously, eventually making their way through the opening in the oögone, and then burying themselves in the substance of the germ-cell (*B*, *z*, Fig. 62). After fertilization, the germ-cell becomes covered with a thick and colored (brown or red) coat, and it then becomes a resting spore.

279. After a period of rest, the resting spore germinates by rupturing its thick coat and permitting the escape of the contents, enclosed in a thin envelope; by this time the protoplasm has divided into four portions, which take on an oval form and develop a crown of cilia. They soon escape from the investing membrane, and after a brief period of activity grow into an ordinary filament in exactly the same manner as the zoöspores.

Practical Studies.—(*a*) In midsummer collect a few quarts of the surface-water of weedy ponds, together with the Pond Scums growing therein; put it into a shallow dish, and after an hour or so look carefully (with the naked eye) for Volvox. It will be seen as a minute green ball (from .5 to 1 millimetre in diameter) rolling slowly through the water. Now carefully transfer it to a slide along with enough Pond Scum to prevent crushing. Under even a low power many of the details of structure may be made out, and one or more young colonies in the interior may almost invariably be seen.

(*b*) Specimens of Œdogonium may be obtained by examining the small sticks and stems of aquatic plants from quiet waters. They may be recognized by the enlarged cells (oögones).

CLASS III. CŒLOBLASTEÆ.

280. The plant-body in this important and interesting class is a branched filament, in which the protoplasm is continuous. These plants are, however, not to be considered single-celled, but rather rows of cells which have not become separated from one another by partitions.

281. **The Green Felts** (*Vaucheriaceæ*) are good representatives of the first order under this class. They are coarse, green, tubular plants which grow in abundance on the moist earth in the vicinity of springs, and in shallow running water, forming dense felted masses.

282. The asexual reproduction consists of a separation of a part of the plant-body, sometimes a swollen lateral branch, sometimes only the protoplasm of such a branch. In the latter case the protoplasm may escape as a zoöspore (*A*, Fig. 63) which eventually forms a wall around itself, and then proceeds to elongate into a new plant-body.

283. Sexual reproduction takes place in lateral branches also. Both antherids and oögones develop as lateral protuberances upon the main stem (*og*, *og*, *h*, Fig. 63). The male organ (antherid) is long and rather narrow, and soon much curved; its upper portion becomes cut off by a partition, and in it very small biciliate antherozoids are developed in great numbers. The female organ (oögone) is short and ovoid in outline, and usually stands near the male organs. In it a partition forms near its point of union with the main stem; the upper portion becomes an oögone, and its protoplasm condenses into a rounded body, the germ-cell: at this time the wall of the oögone opens, and permits the entrance of the antherozoids which were set free by the rupture of the antherid-wall.

284. Upon coming into contact with the germ-cell the antherozoids mingle with it and disappear; the germ-cell immediately begins to secrete a wall of cellulose about itself, and it thus becomes a resting spore. After a period of rest the thick wall of the resting spore splits, and through the opening a tube grows out which eventually assumes the form and dimensions of the full-grown plant.

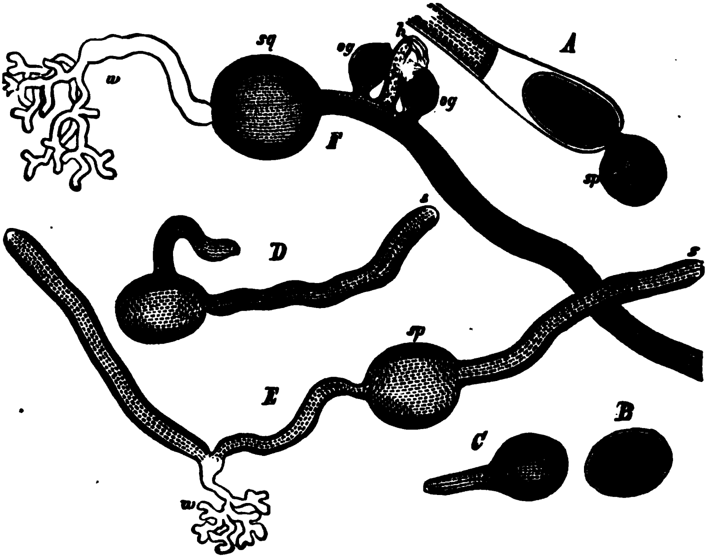

FIG. 63.—Reproduction of Green Felt (Vaucheria sessilis). *A*, formation of a zoöspore; *B*, zoöspore come to rest; *C*. zoöspore germinating; *D*, *E*, young plants; *w*, root-like holdfasts; *F*, plant with sexual organs. Magnified about 30 times.

285. The **Water-Moulds** (*Saprolegniaceæ*) are colorless saprophytes or parasites, more frequently the latter; they are generally to be found in the water, attached to the bodies of living or dead fishes, crayfishes, etc., or occasionally in the moist tissues of animals out of the water. The

plant-body is greatly elongated and branched, and all its vegetative portion is continuous; the reproductive portions only are separated from the rest of the plant-body by partitions.

286. The asexual reproduction is very much the same as in Green Felt. It may be briefly described as follows: The protoplasm in the end of a branch becomes somewhat condensed, a partition forms, cutting off this portion from the remainder of the filament, and the whole of its contents becomes converted by internal cell-division into zoöspores provided with one or two cilia (Fig. 64, 1). These soon escape from a fissure in the wall and are active for a few minutes, after which they come to rest and their cilia disappear (2 and 3). In one or two hours they germinate by sending out a filament (4), from which a new plant is quickly produced.

287. The sexual organs also bear a close resemblance to those of Green Felt. The oögones are spherical, or nearly so (in most of the species), and contain from two to many germ-cells, which are fertilized by means of antherids, which usually develop as lateral branches just below the oögones. In some species the antherids and oögones are upon the same plants, and in such cases the fertilization takes place by the direct contact of the antherid and the passage of its contents into the oögone by means of a tubular process from the former; in other species the plants are diœcious, and in them the antherids produce motile antherozoids, by means of which the fertilization is effected. After fertilization each germ-cell becomes covered with a wall of cellulose and is thus transformed into a resting spore.

288. What is given above may be taken to illustrate the

general mode of reproduction in the order. It presents much variation in the different genera and species. The resting spores of the Water-moulds possess, when mature,

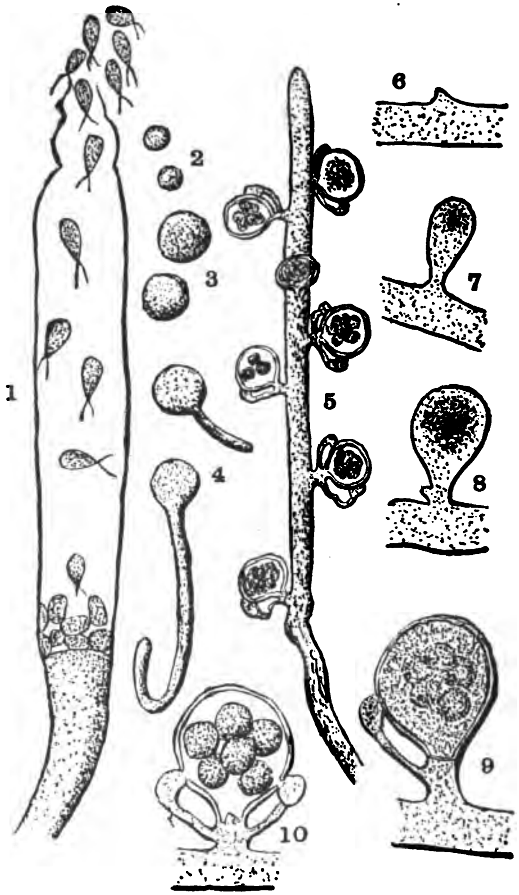

Fig. 64.—Showing reproduction in Water-moulds. 1, 2, 3, 4, asexual reproduction; 5 to 10, sexual reproduction. 6 to 9 show development of oögones and antherids. Highly magnified.

a thick integument, which is double—that is, formed of an outer thicker coat (epispore) and an inner thinner one (endospore). After a considerable period of repose the resting spores germinate by sending out a tube, as in Green Felt.

289. **The Fly-Fungus** (Entomophthora muscæ), which in the autumn is so destructive to house-flies, is a member of a small order (*Entomophthoreæ*) apparently related to the Water-moulds. It consists of small cells which grow in the moist tissues of the fly, and at last pierce the skin, producing minute terminal spores, which give the fly a powdery appearance. These spores (called, also, conidia) may be seen as a whitish halo surrounding the spot to which the fly, now dead, has attached itself. Resting spores have been observed in some species. They are round and thick-walled.

290. **The Mildews and White Rusts** (*Peronosporeæ*) live parasitically in the interior of higher plants. They are composed of long branching tubes, whose cavities are continuous throughout. They grow between the cells of their hosts,* and draw nourishment from them by means of little branches (*haustoria*), which thrust themselves through the walls (Fig. 65).

291. The asexual spores (conidia) are produced upon branches of the

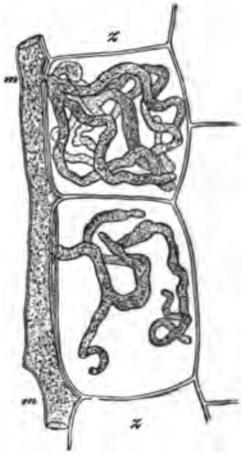

FIG. 65.—Showing one of the hyphæ (*m*, *m*) of a Mildew, sending suckers (haustoria) into the cells (*z*, *z*) of its host. Magnified 300 times.

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* In speaking of a parasite, the plant or animal upon which it feeds is called its *host*.

fungus which protrude through the epidermis of the host. In the Mildews (species of Peronospora) these branches find their way through the breathing-pores, and bear their spores singly upon lateral branchlets (Fig. 66); in the White Rusts (species of Cystopus) the conidia-bearing branches collect under the epidermis and rupture it. Here the conidia are borne in chains or bead-like rows (Fig. 67).

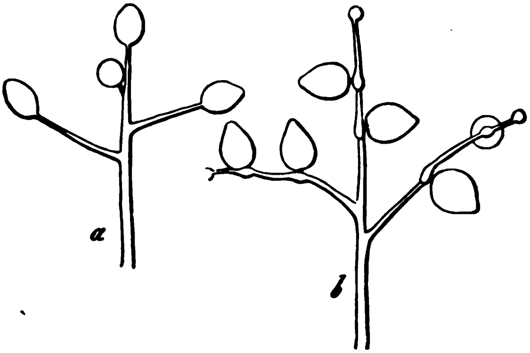

FIG. 66.—Showing tips of two conidia-bearing branches of Potato-mildew (Peronospora infestans). Highly magnified.

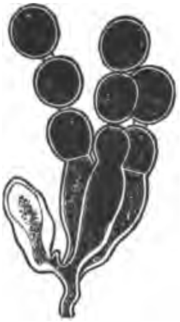

FIG. 67.—Showing the tips of three conidia-bearing branches of the White Rust of Peppergrass. Magnified 400 times.

292. In some species the conidia germinate by forming a tube; in others they divide internally and finally emit many zoöspores. The latter eventually protrude a tube and bore their way into the cells of the host (Fig. 68, *a* to *i*).

293. The sexual reproduction always takes place in the intercellular spaces of the host. Lateral branches of two kinds appear upon the hyphæ; those of one kind (the young

oögones) become greatly thickened and finally assume a globular shape (Fig. 69, *o*); the other branches (the young antherids) become elongated and club-shaped (Fig. 69, *n*).

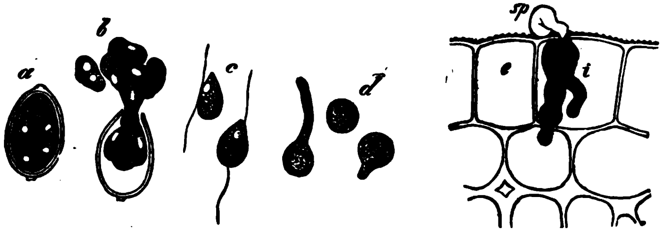

FIG. 68.—Germination of the conidia of Potato-mildew. *a*, *b*, *c*, formation of zoöspores; *d*, growth of zoöspores; *sp*, a zoöspore growing into the cells of the plant, *e*, *i*. Magnified about 400 times.

The antherids bend and come in contact with the oögones, and soon each thrusts out a small tube which penetrates the oögone, reaching the germ-cell. The protoplasm of the antherid is thus transferred directly to the germ-cell (Fig. 69, *A*, *B*, *C*). After fertilization the germ-cell secretes a thick double wall, and so becomes a resting spore.

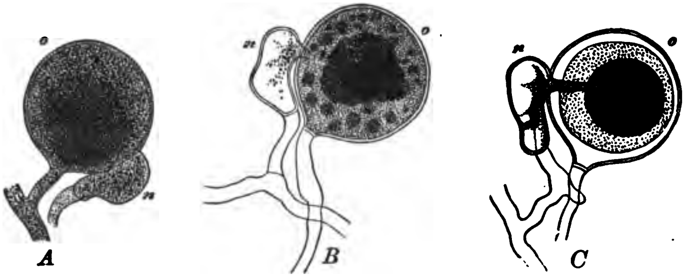

FIG. 69.—Sexual organs of a Mildew. *o*, oögones; *n*, antherids. *A*, youngest stage; *B* and *C*, older stages. Magnified 350 times.

294. The resting spores remain in the tissues of the host until the latter decay, which is generally in the spring.

Germination then takes place, in some species by the production of a tube, in others by the division of the proto-

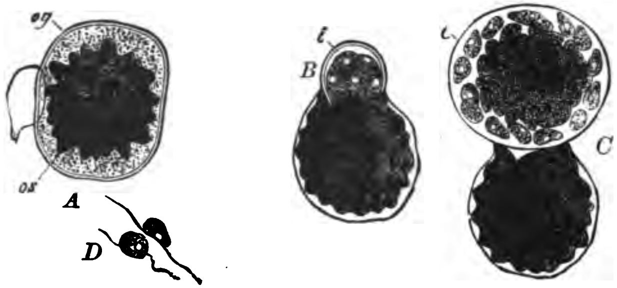

FIG. 70.—Resting spores of White Rust of Peppergrass; at *A*, still surrounded by oögone. *B*, *C*, formation of zoöspores; *D*, free zoöspores. Magnified 400 times.

plasm into zoöspores (Fig. 70, *B*, *C*, *D*) whose subsequent development is like that described above in case of the conidia.

Practical Studies.—(*a*) Collect a quantity of Green Felt and preserve it in a dish of water. After a few hours a large number of zoöspores may be observed collected at the edge of the water nearest to the light.

(*b*) Examine carefully mounted specimens of the bright-green filaments, and look for the thickened lateral branches which produce the zoöspores.

(*c*) Select some of the oldest, yellowish filaments. Mount and examine with a low power for the sexual organs. In collecting specimens for the study of the sexual organs it is necessary always to take those masses which are yellowish and appear to be dying or dead.

(*d*) Throw a dead fish into a pool of water in the summer, and examine it after a few days, when it will probably be found covered with a mould-like growth. Remove a few filaments and look for the formation of zoöspores. The same Water mould (Saprolegnia ferax) may often be found upon the bodies of young fishes, especially in fish-hatching houses.

(*e*) In the latter part of summer and in the autumn, examine the dead flies which adhere to window-panes, door-casings, and especially to wires and strings hanging from the ceiling. The whitish powder around the fly will indicate the presence of the Fly-fungus. Mount some of this white powder in water and study under a high power to see spores. Examine some of the tissue of the fly (by tearing out small bits of the distended abdomen) for the internal portion of the parasite.

(*f*) In the spring the leaves of shepherd's purse and peppergrass may often be found covered underneath with a white mould-like growth (Peronospora parasitica). Carefully scrape off a little of this growth and mount first in alcohol, afterwards adding a little potassic hydrate. The irregularly branching hyphæ will be seen to bear here and there their white, broadly ellipsoidal conidia. Similar studies may be made of the Grape-mildew (Peronospora viticola) on grape-leaves in autumn, and the Lettuce-mildew (Peronospora gangliformis) on cultivated and wild lettuce from spring to autumn.

(*g*) Make very thin cross-sections of a leaf affected with a Mildew, when the latter has passed the period of its greatest vegetative activity. Mount in alcohol (to drive out air-bubbles), then add potassic hydrate, and look for the resting spores, which in some species are of a dark-brown color.

(*h*) White Rusts occur on many plants: one (Cystopus candidus) on shepherd's purse, peppergrass, radish, etc.; another (C. bliti) on amarantus; and another (C. portulacæ) on purslane. For conidia, make very thin cross-sections of leaves, through a white-rust spot, and mount as above. The resting spores (which are dark brown) are easily obtained in the leaves of amarantus and purslane.

CLASS IV. FUCACEÆ (*the Rockweeds*).

295. The plants of this class are entirely marine. In many cases the development of the plant-body is unusually perfect, showing a differentiation into parts which have a considerable resemblance to roots, stems, and leaves. In size they approach the flowering plants. Their tissues, too, show a high degree of differentiation; the cells are arranged in cell-masses, and these are differentiated into several varieties of parenchyma, approaching, in some instances, to the condition which prevails in the Mosses and their allies.

296. With the foregoing there is found a marked differ-

entiation of portions of the plant-body into general reproductive organs, analogous to the floral branches of higher plants. The sexual organs are developed upon modified branches, which differ more or less in shape and appearance from the ordinary ones.

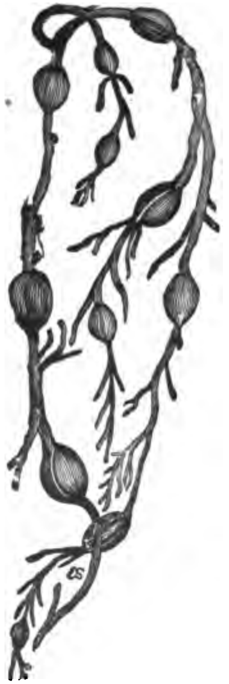

FIG. 71. Part of a plant of knotted Rockweed (Ascophyllum nodosum), showing the air-bladders. Natural size.

297. In **Rockweed** (Fucus) the sexual organs are found in the thickened ends of the lateral branches (*A*, Fig. 72). They occur on the walls of cavities termed *conceptacles*, which are spherical, with a small opening at the top (*B*, Fig. 72). The conceptacles are at first portions of the general surface, and afterward become depressed and walled in by the overgrowth of the surrounding tissues; they are thus in reality portions of the general surface.

298. The walls of the conceptacles are clothed with pointed hairs, which in some species project through the opening, and among these are found the sexual organs, which are themselves, as Sachs has pointed out, modified hairs. The antherids are produced as lateral branches of hairs (*A*, Fig. 73); each antherid is a thin-walled cell, whose protoplasm breaks up into a large number of biciliate antherozoids, which escape by the rupture of the surrounding wall (*B*). Before rupturing, however, the antherids detach themselves and float in the water with their contained antherozoids.

299. The oögone is a globular or ovoid short-stalked body containing eight germ-cells. The germ-cells escape from the oögone surrounded by an investing membrane, which floats out through the opening of the conceptacle, where it finally ruptures and sets the germ-cells free (*II*, Fig. 73). The antherozoids, which are liberated at about the same time, gather around the inactive germ-cells in great numbers, and by the vigor of their movements sometimes actually give them a rotary motion (*III*). The re-

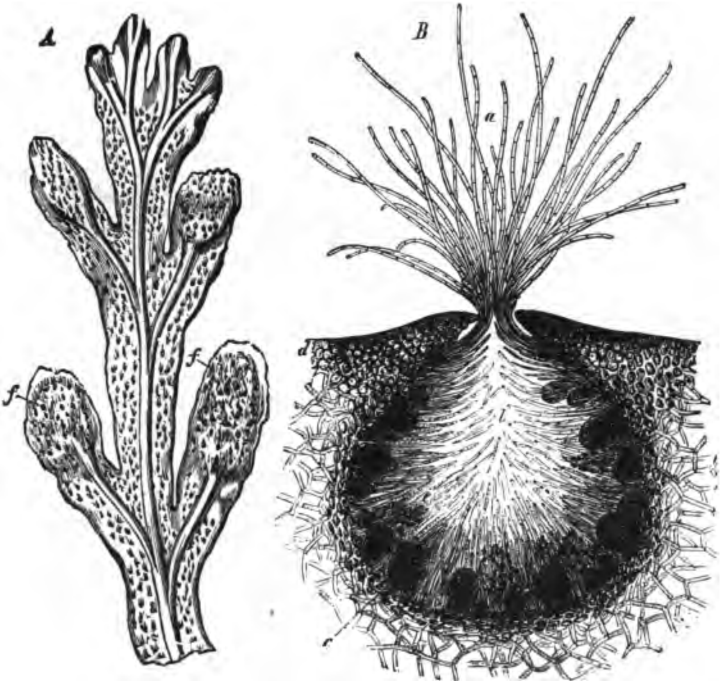

FIG. 72.—*A*, end of branch of a Rockweed (Fucus evanescens), natural size; *f*, *f*, conceptacles. *B*, magnified section through a conceptacle, showing hairs, *a*, *b*; oögones, *c*; antherids, *e*.

sult of their coming together is the fertilization of the germ-cells, and their transformation into resting spores by the secretion of a wall of cellulose on each one.

300. In germination the resting spore lengthens and undergoes division into numerous cells; at the same time it elongates below into root-like processes, which serve to hold fast the new plant (*V*, *IV*).

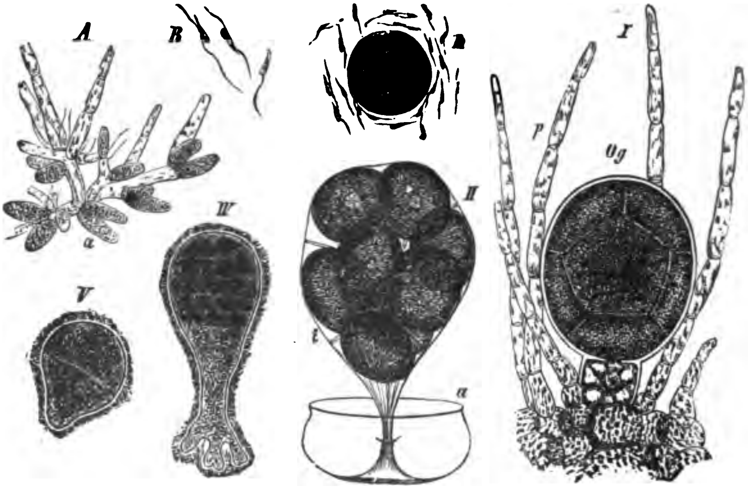

FIG. 73.—Sexual organs of Rockweed (F. vesiculosis). *A*, antherids; *B*, antherozoids; *I*, oögone and hairs; *II*, escape of germ-cells; *III*, germ-cell surrounded by antherozoids; *IV*, *V*, germination of resting spore. Magnified 160 times; *B*, 360.

Practical Studies.—(*a*) Secure specimens of Rockweeds, fresh or dry. Fresh ones may easily be found along the beach of the ocean after a storm. Dry specimens can easily be procured by purchase or exchange. Make thin cross-sections through the conceptacles in the thickened ends of the branchlets. When mounted in water, even the sections from the dry specimens will frequently show the sexual organs quite well. It must be remembered that some species are diœcious, i.e., have the antherids on one plant and the oögones on another.

(*b*) Make very thin cross and longitudinal sections of different portions of the plant-body, and study the tissues. Note particularly the boundary tissue (epidermis), and the cells constituting the midribs and harder portions of the stems and leaves.

(*c*) The following key to the genera of American Fucaceæ will be helpful in their study.

I. Plant branched:

  1. Leafy; air-bladders stalked, separate.........Sargassum.
     In addition to half a dozen species of both coasts, the Gulfweed (Sargassum bacciferum) may be mentioned, which floats in great quantity in mid-Atlantic, constituting the so-called Sargasso Sea. Its proper home is in the West Indian region, where it grows attached to rocks.
  2. Leaves spirally inserted, bearing air-bladders on their blades (Southern)........................Turbinaria.
  3. Leaves 2-ranked, bearing air-bladders on their petioles (Western)...............................Phyllospora.
  4. Plant pinnatifid; air-bladders several celled, terminal on the branchlets (Western)....................Halidrys.
  5. Plant dichotomous, the parts flat and provided with a midrib (both coasts)..............................Fucus.
     This contains the proper Rockweeds of the seaside. Eight species occur in the United States.
  6. Plant irregularly dichotomous, the linear parts destitute of a midrib (Eastern)...................Ascophyllum.
  7. Plant much-branched, bushy, the branches filiform (Western)......................................Cystoseira.

II. Plant reduced to a top-shaped or cup-shaped vesicle (doubtfully American)........................Himanthalia.

CHAPTER X.

BRANCH IV. CARPOPHYTA.

THE SPORE-FRUIT PLANTS.

301. The distinguishing characteristic of the plants which constitute this vast division is the formation of a spore-fruit (sporocarp) as a result of fertilization. The spore-fruit consists essentially of two different parts; viz., (1) a fertile part, which either directly or indirectly produces spores, sometimes a few, or even one, or a very great number; (2) a sterile part, consisting of cells or tissues developed from the cells adjacent to the fertile part, and so formed as to envelop it.

302. This immense group includes plants with chlorophyll, and a large number of species which are parasitic or saprophytic, and which, as a consequence, are destitute of chlorophyll. In the former, the spore-fruit is small in proportion to the size of the vegetative parts of the plant; but in the latter, where the vegetative parts are greatly reduced, the spore-fruit is proportionately large. In this the parasites and saprophytes of the Carpophyta are like those of the flowering plants, in which the vegetative or assimilative organs are smaller than in those which contain chlorophyll; thus the very large spore-fruits of many of the larger fungi, and their relatively small mycelium, may be compared to the large reproductive organs and the re-

duced stems and leaves of the Vine-rape of Sumatra (Rafflesia).

303. The female organ in this division is called a carpogone, and consists of a single enlarged cell, or of several cells of a special form. In some cases a projection, called the trichogyne, is attached to the carpogone; its function appears to be the conveyance to the carpogone of the fertilizing matter received from the antherid.

304. The antherid is much more variable in structure than the female organ. In some cases it is applied directly to the carpogone in fertilization, while in others it produces antherozoids.

305. The plant-body shows in general a more perfect development in the Carpophyta than in the preceding divisions. While it is but little developed in the parasitic and saprophytic species, it is well developed in many of the Red Seaweeds and the Stoneworts, in which there is often a considerable amount of differentiation of the plant-body into caulome and phyllome.

306. Five classes may be readily distinguished, as follows:

1. Green fresh-water plants; fruit-spores few.......... *Coleochæteæ.*
2. Red or purple mostly marine plants; fruit-spores many.. *Florideæ.*
3. Parasites; fruit-spores many, enclosed in sacs........ *Ascomycetes.*
4. Parasites; fruit-spores many, on stalks............ *Basidiomycetes.*
5. Green fresh-water plants; fruit-spore one............. *Characeæ.*

CLASS I. COLEOCHÆTEÆ.

307. The genus **Coleochæte** shows us the simplest form of sexual reproduction among the Carpophytes. The species are all small green fresh-water plants, composed of branching filaments, which are arranged radially; the diameter of each cushion-like mass is from 1 to 2 mm. (.04 to .08 in.),

308. Asexual reproduction is by means of ciliated zoöspores, one of which may form in each cell and escape through a round hole in the cell-wall (*D*, Fig. 74).

309. In the sexual process the female organ, the carpogone, is a single cell, wide below and tapering above into a long slender canal, the trichogyne, which is open at its apex (*A*, *og*, Fig. 74). In the swollen basal portion there is a considerable mass of protoplasm, which is the essential part to be fertilized. The male organs, the antherids, are formed as flask-shaped protuberances which grow out of adjoining cells. In each antherid a single oval biciliate antherozoid is formed (*A*, *z*, *z*, Fig. 74).

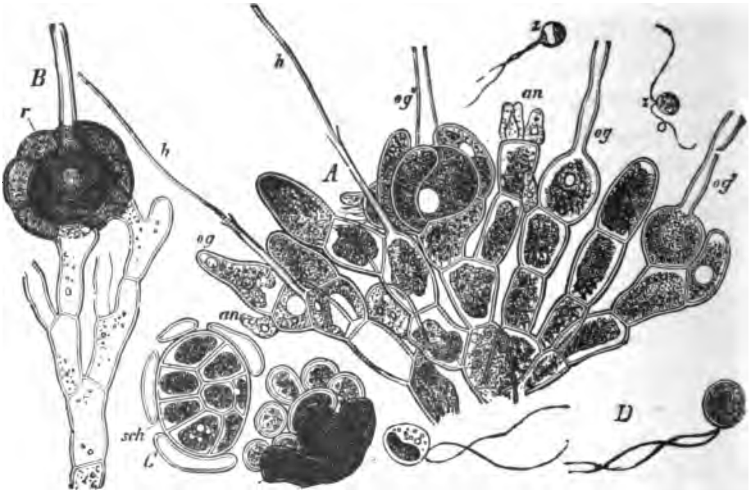

FIG. 74.—Coleochæte. *an*, antherids; *og*, carpogones, each with a trichogyne; *z*, *z*, antherozoids; *B*, fertilized carpogone, surrounded by the covering, *r* ("pericarp"), the whole forming the spore-fruit; *C*, spore-fruits burst open, showing interior tissues; *D*, zoöspores from *C*. Magnified 350 times.

310. Fertilization is doubtless effected by these antherozoids coming in contact with the protoplasm of the carpo-

gone, but the actual entrance of the former has not yet been seen. After fertilization the protoplasm in the carpogone increases considerably in size, and forms a cellulose coat of its own. The cells which support the carpogone send out lateral branches, which grow up and closely surround it, finally covering it entirely (excepting the trichogyne) with a cellular thick-walled "pericarp" (*B*, *r*). The whole mass, including the fertilized carpogone and its investing pericarp, constitutes the simplest form of spore-fruit (the *sporocarp*).

311. The further growth of the spore-fruit takes place the next spring by the swelling of the protoplasmic contents, and the consequent rupture of the pericarp; the inner portion divides into several cells, C (the proper fruit-spores), which give rise to zoöspores closely resembling those developed from the vegetative cells. From each zoöspore a new plant eventually arises.

Practical Studies.—(*a*) These little plants occur in fresh-water pools as little green masses adhering to leaves, sticks, etc. According to Wood, we have probably two species.

(*b*) The sexual process and the development of the sexual organs occur in May, June, and July.

CLASS II. FLORIDEÆ (*the Red Seaweeds*).

312. The plants of this class, which are almost without an exception marine, are among the most beautiful and interesting members of the vegetable kingdom. All have some shade of red or purple which sometimes becomes exceedingly rich; while for beauty of outline and delicacy of branching they stand unrivalled among plants.

313. To a great extent they grow in the deep water below low-water mark, far beyond the reach of the ordi-

nary collector. There is therefore a good deal of difficulty involved in their study. The greater part of the material which the student secures for study is that which the storms have washed ashore from the deeper waters.

314. The plant-body varies from small branching filaments, on the one hand, to expanded leaf-like growths showing a considerable degree of complexity, with the beginning of a differentiation of the cells into several kinds of tissues. All contain chlorophyll, which, however, is generally hidden by the presence of a red or purple coloring matter.

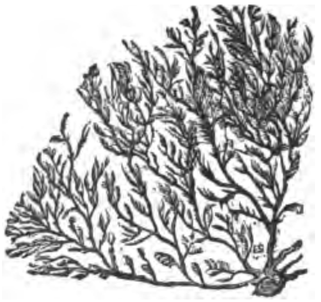

FIG. 75.

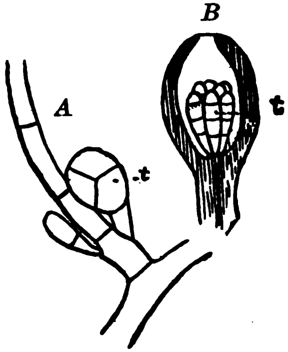

FIG. 76.

FIG. 75.—A Red Seaweed (Plocamium coccineum). About natural size.

FIG. 76.—Tetraspores of Red Seaweeds. *A*, of Lejolisia mediterranea; *t*, tetraspores. *B*, of Corallina officinalis; *t*, tetraspores in a cup-shaped extremity of a branch.

315. The asexual reproduction takes place by means of spores, which, from almost always forming in fours, are known as tetraspores (*A* and *B*, *t*, *t*, Fig. 76). These appear to replace the swarm-spores of other seaweeds, and may also be compared to the conidia of certain fungi; they are destitute of cilia, and are, as a consequence, not locomotive.

316. The sexual organs consist of carpogones and antherids. The latter are situated singly or in groups on the ends of branches (*A* and *B*, *a*, *a*, Fig. 77). The antherozoids are small round bodies which are destitute of cilia (*A*, *x*, Fig. 77), and are carried about by currents of water, and in this way brought to the carpogones.

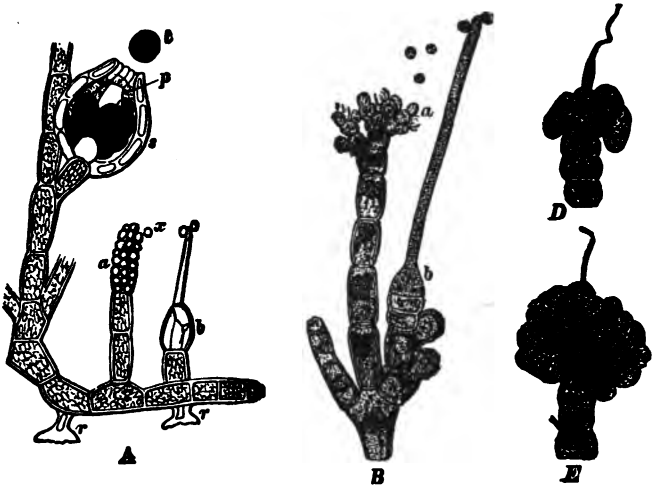

Fig. 77.—Sexual reproduction of Red Seaweeds. *A* (Lejolisia): *a*, antherid; *x*, antherozoids; *b*, carpogone, with antherozoids attached to the trichogyne; *s*, section of ripe spore-fruit, from which a spore (fruit-spore) is escaping. *B* (Nemalion): *a*, antherid, and antherozoids; *b*, carpogone. *D* and *E*, development of spore-fruit. Magnified 150 times.

317. The carpogones are somewhat variable as to their complexity, being much more simple in the lower orders than in the higher. In some cases (Nemalion) the carpogone (*B*, *b*, Fig. 77) is thickened below, and elongated above into the trichogyne, which differs from that in Coleochæte in not being open at the top.

318. When the antherozoids are set free from the anther-

ids they attach themselves to the trichogyne, as shown in Fig. 77. The result of this contact of the antherozoids with the trichogyne is the fertilization of the carpogone, which immediately enlarges and at the same time undergoes division into many cells, which grow into short, crowded branches, bearing a spore at the end of each (*D* and *E*, Fig. 77). This growth, which includes the spores and the short branches which bear them, and which resulted from the fertilization of the carpogone, is the spore-fruit (*sporocarp*) of these plants. In the genus under consideration the spore-fruit is a comparatively simple growth, as compared with the degree of complexity it reaches in some other orders of this class.

319. In some other cases (Lejolisia, etc.), the carpogone, before fertilization, consists of several cells (*A*, *b*, Fig. 77). Upon fertilization taking place, the outer cells of the carpogone divide, and develop into articulated branches which lie side by side and form a more or less spherical envelope, the so-called "pericarp." In the mean time the central cell of the carpogone produces outgrowths or short branches which eventually bear spores, occupying the cavity of the pericarp (*A*, *s*, Fig. 77). The spore-fruit here consists of a fertile part which bears spores, and a sterile part which serves as a protection or covering. In technical works the spore-fruit is called a "cystocarp."

Practical Studies.—There are many orders of the Red Seaweeds, but it is unnecessary to notice them here particularly. About one hundred species occur along the New England coast, and the number is greatly increased as we pass to the southward.

It is difficult for the student to study the plants of this class away from the seashore, and as a rule it is perhaps as well for the beginner to content himself with only a general examination of such specimens as may be accessible.

Specimens for the study of the structure should be preserved in alcohol or glycerine. However, much may be made out by the careful examination of dried specimens.

Red Seaweeds may often be obtained "in the rough" which can be slightly moistened and then pressed out and dried for study. Such material will often yield quite good specimens.

Good mounted microscopic specimens may sometimes be obtained showing the structure of the plant as well as of the sexual and asexual reproductive organs.

CLASS III. ASCOMYCETES (*the Sac-Fungi*).

320. This large class includes chlorophyll-less plants which differ much in size and appearance, but which agree in producing their fruit-spores (sac-spores, or *ascospores*) in sacs (*asci*).

321. The sexual organs consist of carpogones and antherids, and, after fertilization, produce a spore-fruit (sporocarp) which includes the sacs and their contained sac-spores. The most common number of sac-spores is eight in each sac; but it sometimes exceeds, and frequently falls short, of this number, there being often no more than one or two. The sacs are in many cases arranged side by side in a compact mass, forming a spore-bearing surface (the *hymenium*).

322. In addition to the sac-spores there are generally one or more other kinds of spores which are developed asexually. Some of these are doubtless to be regarded as the equivalents of the conidia of the lower groups, and will accordingly be so named here.

Of the Sac-fungi there are a number of well-marked orders, all but one of which are popularly known as fungi.

323. **The Blights and their Allies** (*Order Perisporiaceæ*).—These plants, which are mainly parasitic, are composed of branching jointed filaments (*hyphæ*) which form a white web-like film upon the surface of the leaves and stems of their hosts. There are both sexual and asexual

spores, and of the latter there are in most cases two or three different kinds, which are produced earlier than those that result from a fertilization.

324. The sexual organs and the spore-fruit resulting from the act of fertilization bear a striking resemblance to those of Coleochæte, the difference being such as may be accounted for by taking into consideration the aquatic habits of the one and the aerial and parasitic or saprophytic habits of the other.

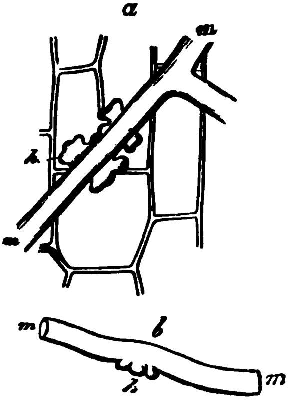

FIG. 78.

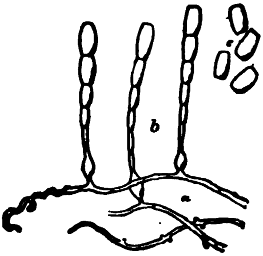

FIG. 79.

FIG. 78.—Grape-blight (Erysiphe). *a*, a piece of a vegetative hypha, *m*, *m*, upon a fragment of the epidermis of the leaf of the grape, and to which it is fastened by the suckers, *h*; *b*, hypha, with the suckers, *h*, seen in side view. Magnified 370 times.

FIG. 79.—Grass-blight (Erysiphe communis). *a*, vegetative filaments, with a few suckers; *b*, branches bearing conidia; *c*, separated conidia. Magnified 135 times.

325. In the Blights, which are all parasitic, the jointed filaments closely cover the leaves and other tender parts of their hosts, and draw nourishment from them by means of suckers, which project as irregular outgrowths from the side next to the epidermis (Fig. 78). These suckers apply themselves closely to the epidermal cells, and, in some cases, appear to penetrate them.

326. The crossing and branching filaments soon send up many vertical branches, in which partitions form at regular intervals. The cells thus formed are at first oblong and cylindrical, with flattened ends; but the topmost one soon becomes rounded at its extremities, and the others follow in quick succession, thus giving rise to a row of cells, the spores, or *conidia* (Fig. 79). These fall off and germinate at once by pushing out a tube, which gives rise to a new plant.

327. The sexual process in most species takes place late in the season. Two filaments crossing each other or coming into close contact swell slightly and send out from each a short branch; one of these becomes the carpogone (*c*, Fig. 80). From the swollen part of the other filament a corresponding branch is given off, which grows up in contact with the carpogone and becomes the antherid (*b*, Fig. 80).

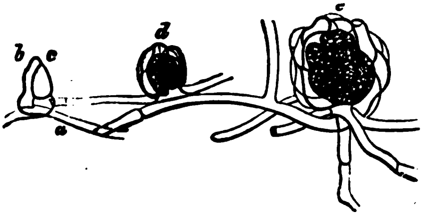

FIG. 80.

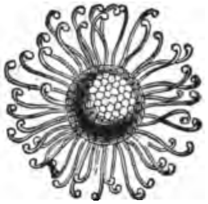

FIG. 81.

FIG. 80.—The sexual process in a Blight (Erysiphe). *a*, jointed threads; *b*, antherid; *c*, carpogone; *d*, young spore-fruit; *e*, older spore-fruit. Magnified.

FIG. 81.—Ripe spore-fruit of Willow-blight (Uncinula adunca). The appendages are curved or hooked. Magnified.

328. Fertilization at once takes place, by the direct union of protoplasm. Eight or ten branches grow out just below the carpogone, and growing upward soon completely cover it with a cellular coat which eventually becomes hardened and turns brownish in color, constituting the pericarp of the spore-fruit (Fig. 81).

329. The carpogone inside of the pericarp gives rise, by branching, to one or more large cells filled at first with granular protoplasm, which soon forms two to eight spores (Fig. 82). Upon its outer surface the spore-fruit develops long filaments (known as *appendages*), probably for holdfasts. In some genera these terminate in hooks (Fig. 81); others are dichotomously branched; still others are needle-shaped; while many end irregularly. The spore-fruits remain during the winter upon the fallen and decaying leaves, and finally, by rupturing, permit the sacs, with the contained spores, to escape.

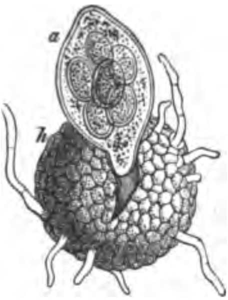

FIG. 82.—A ruptured spore-fruit of Gooseberry-blight, showing the escaping sac, with its contained spores. Magnified about 270 times.

330. The Herbarium-mould (Eurotium) is a near relative of the Blights. It is common on poorly dried specimens in the herbarium, and also on decaying fruits, wood, etc. It sends up vertical branches, which swell at the top and bear a great number of small protuberances (the *sterigmata, A, c, st,* Fig. 83), each of which produces a chain of conidia.

331. The sexual organs appear a little later than the conidia. The end of a branch of the plant becomes coiled into a hollow spiral (*A, as,* Fig. 83), which constitutes the carpogone. From below the spiral an antherid grows upward, and brings its apex in contact with the upper cells of the carpogone (*B,* Fig. 83).

332. After fertilization, other branches grow up around the carpogone, and finally completely enclose it, as in the Blights described above (*C, D,* Fig. 83). In the mean time, from the cells of the enclosed carpogone branches

bud out, and finally produce many eight-spored sacs on their extremities; after a time the sacs are dissolved, and the spore-fruit, now of a sulphur-yellow color, contains a multitude of loose spores.

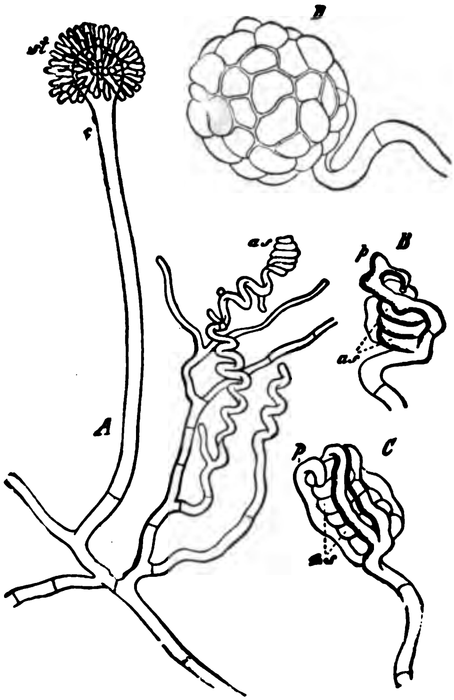

FIG. 88.—Eurotium. *A*, a portion of the plant, with erect hypha, *c*, bearing at its top a radiating cluster of sterigmata, *st*, from which the conidia have fallen; *as*, young carpogone—below it a younger branch is beginning to coil spirally to form another carpogone. *B*, the carpogone, *as*, and the antherid, *p*. *C*, the same beginning to be surrounded by the enveloping branches which grow out from its base. *D*, spore-fruit. Highly magnified.

Practical Studies.—(*a*) Collect in the autumn a quantity of leaves of the lilac which are covered with a whitish mould-like growth, the Lilac-blight (Microsphæra friesii). Scrape off a bit of this Blight, after moistening with a drop of alcohol; mount carefully, adding a little potassic hydrate. Look for conidia and suckers (haustoria) Look also for spore fruits, which appear like minute dark dots to the naked eye. Carefully crush the spore-fruits and observe the sacs (4 to 7) with their contained spores (6). Notice the beautifully branched tips of the appendages.

(*b*) Collect and study the blights to be found on hops (Sphærotheca castagnei), on cherry- and apple-leaves (Podosphæra tridactyla), on hazel- and ironwood-leaves (Phyllactinia suffulta), on willow-leaves (Uncinula adunca), on leaves and fruit of grapes (U. americana), on wild sunflowers, verbenas, etc. (Erysiphe lamprocarpa), on peas (E. martii), on grass, anemones, buttercups, etc. (E. communis).

(*c*) Place a few slips of green twigs in an ordinary plant-press, allowing them to remain until they become (1st) mouldy (conidial state), and (2d) covered with minute yellow globular bodies (the spore-fruits). These are known as the Herbarium-mould (Eurotium herbariorum). Study as in case of the blights.

333. **The Truffles** (*Order Tuberaceæ*) are well known from their large underground spore-fruits, which are edible. Internally there are narrow tortuous channels on whose walls sacs develop, each containing a number of spores (Fig. 84). Little is known of their round of life, and the sexual organs have not been discovered.

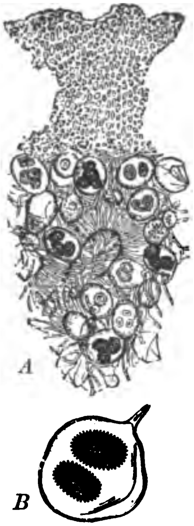

FIG. 84.—*A*, a small slice of the spore-fruit of a truffle (Tuber melanosporum), showing sacs and spores; *B*, a sac and its spores, more enlarged.

334. The Blue Moulds (species of Penicillium) are members of this order, and are in reality minute truffles. The conidial stage is the common Blue Mould on decaying fruit and pastry (Fig. 85). The sexual organs resemble those of the herbarium-mould, and the spore-fruit is a minute truffle-like body as large as a coarse sand-grain.

Practical Studies.—(*a*) Truffles are natives of Europe, but they may be obtained for study in our markets.

(*b*) Blue Mould may be obtained from decaying fruit, pastry, and frequently upon ink.

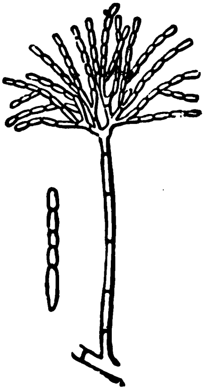

FIG. 85.—A filament of Blue Mould (Penicillium chartarum), bearing conidia. At the side is shown an isolated chain of conidia.

335. **The Cup-Fungi and their Allies (*Order Helvellaceæ*).**—The common Cup-fungus of the woods is a good representative of this order. The familiar cup- or saucer-shaped growth is in reality the spore-fruit, while the plant itself generally grows underground. The plant consists of whitish, jointed filaments which grow on or in the ground, drawing their nourishment from decaying sticks, roots, etc.

336. But little is known as to the asexual reproduction, but in some species conidia much like those in the preceding orders have been observed.

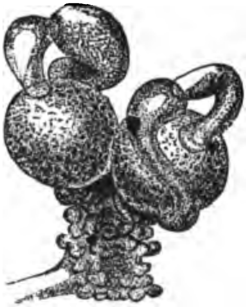

FIG. 86.—Sexual organs of a Cup-fungus (Peziza omphalodes). The two carpogones are globular; each has a curved trichogyne. The antherids are curved branches from below the carpogones. Much magnified.

337. The sexual organs are produced by the swelling up of the ends of certain of the white filaments of the plant into globular or ovoid cells, the carpogones, each having a projection (trichogyne). From below each carpogone a slender branch grows out, and becomes the antherid (Fig. 86).

338. Fertilization takes place by the antherids coming in contact with the trichogyne. As a result, numerous branches start out from below the carpogone, and growing upward form a dense felted mass which gradually takes on

the size and form of the spore-fruit. Some of the filaments of the spore-fruit become enlarged into sacs in which spores are developed (Fig. 88), while the others make up the sterile or protective tissue. The spore-sacs grow so that all reach the same height, and make up the inner surface of the cup (Fig. 87).

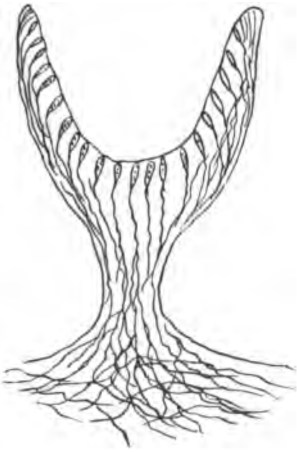

Fig. 87.

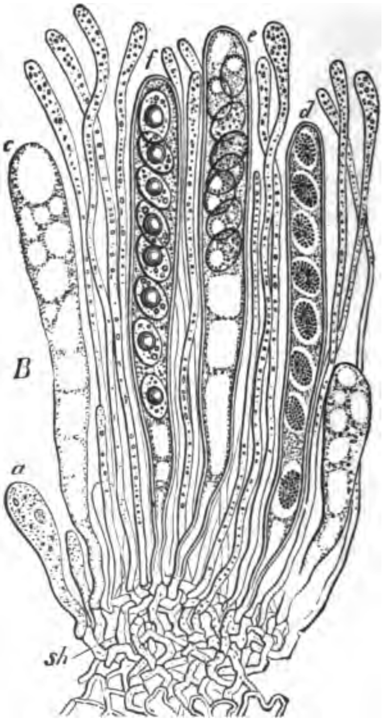

Fig. 88.

Fig. 87.—Diagrammatic vertical section of a Cup-fungus, showing position of the spore-sacs.

Fig. 88.—A few spore-sacs of a Cup-fungus (Peziza convexula), in various stages of development. *a*, youngest, to *f*, oldest. The slender filaments (paraphyses) belong to the sterile tissue. Magnified 550 times.

Practical Studies.—(*a*) Search for cup shaped fungi, in the spring, about old hot-beds and upon well-rotted barnyard-refuse. The common Cup-fungus of an amber color (Peziza vulgaris) often to be met with in such localities is one of the best for the study of spores and spore-sacs. Make very thin sections at right angles to the inner surface. This species may be readily preserved in alcohol for future study.

(*b*) Collect the bright-red saucer-shaped plants growing in the woods upon decaying sticks and having a diameter of 1 to 4 cm. Make similar sections.

(*c*) Collect a few Morels (Morchella esculenta), and make sections at right angles to the surface of the pits which cover its upper portion, for spores and spore-sacs. The Morel, which grows in the woods, is an amber- or straw-colored fungus 10 to 15 cm. high and having an egg-shaped pitted top, 3 to 6 cm. in diameter, borne upon a thick stalk, both stalk and top being usually hollow. The whole growth above ground (which is edible) is to be regarded as a spore-fruit.

339. **The Black Fungi** (*Order Pyrenomycetes*).—The plants of this order are parasitic or saprophytic in habit; their tissues are usually hard and somewhat coriaceous, differing in this respect from the Cup-fungi, which are generally fleshy. In many respects the Black Fungi are much like the Cup-fungi, to which they are doubtless closely related.

340. A good illustration of the plants of this order is the Black Knot (Plowrightia morbosa) which attacks the plum and cherry. In the spring the parasitic filaments, which the previous year penetrated the young bark, multiply greatly, and finally break through the bark and form a dense tissue. The knot-like mass grows rapidly, and when full-sized is usually from two or three to ten or fifteen centimetres long (.8 or 1.2 to 4. or 6. in.), and from one to three centimetres in thickness (.4 to 1.2 in.); it is solid and but slightly yielding, and is composed of filaments intermingled with an abnormal development of the bark-tissues of the host-plant.

341. The knot at this time is dark-colored, and has a

velvety appearance, which is due to the fact that its surface is covered with myriads of short, jointed, vertical filaments, each of which bears one or more conidia (Fig. 89, 1). The conidia, which fall off readily, are produced until the latter part of summer, when the filaments which bear them shrivel up and disappear.

342. During the latter part of summer spore-sacs are produced, but require the greater part of winter to come to perfection. The spore-sacs grow in the cavities of minute papillæ (*perithecia*), and are intermingled with slender filaments (paraphyses, 3 and 4, Fig. 89). Each spore-sac contains eight spores, which eventually escape through a pore in the top of the sac. These spores germinate by sending out a small filament, or sometimes two (Fig. 89, 6).

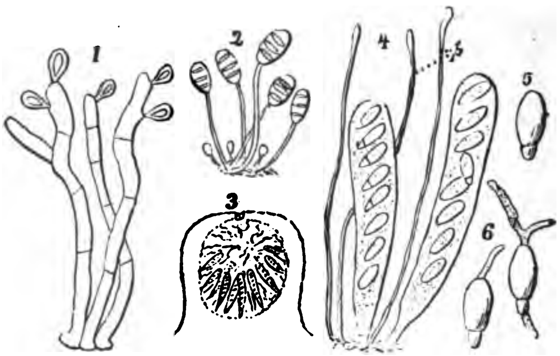

FIG. 89.—Structure of Black Knot. 1, filaments bearing conidia; 2, stylospores: 3, a hollow papilla (perithecium) containing spore-sacs; 4. spore-sacs and spores, with three slender filaments (paraphyses); 5, a spore; 6, spores germinating. All much magnified.

343. Besides the perithecia, there are other cavities found which much resemble them and contain other supposed reproductive bodies.

344. No sexual organs have as yet been observed.

Possibly they exist in the dense tissues of the knot, and fertilization probably occurs in the spring or early summer, while the conidia are being produced on the surface of the young knot.

345. The parasitic filaments of each year's knot generally penetrate downward some centimetres into the uninjured bark, and remain dormant there until the following spring, when they begin the growth which results in the production of a new knot, as described above.

346. The Black Fungi include a large number of exceedingly injurious species; they often attack and destroy not only plants, but also insects, upon which their ravages are in many cases very great.

347. To this order belongs the Ergot (a common parasite upon heads of rye), and also many of the black growths upon the bark and wood of trees. Many species produce black spots upon living leaves, while many others occur upon dead leaves and twigs.

Practical Studies.—(*a*) In early summer examine the Choke-cherry and Plum trees (wild and cultivated) for the young stages of Black Knot. Watch the development until the knot becomes velvety in appearance (about midsummer). Now make very thin cross-sections of the knot and examine for conidia.

(*b*) Late in autumn and in early winter examine the knots on the same trees. Note the young perithecia, i.e. hollow papillæ. Make very thin vertical sections through some of these. No perfect spores can be found at this time.

(*c*) Collect fresh knots in midwinter and make similar examinations, when the sacs and spores will be found.

NOTE.—The several stages may be readily preserved in alcohol for future study.

348. **The Lichens** (*Order Lichenes*) are among the most interesting plants of the vegetable kingdom. They are not only often of exceeding beauty, but their structure and their mode of life are in some respects very wonderful,

They abound almost everywhere—on tree-trunks, rocks, old roofs, and in many regions upon the ground. They are for the most part of a greenish-gray color, and hence are often called Gray-mosses. Other colors, as black, purple, yellow, and white, are also common.

349. They are all of rather small size, varying from a millimetre or so to 20 or 30 cm. in length. For the greater part the plant-body is flattish, and adherent to the surface upon which it grows (*A*, Fig. 90), but some species have more or less elongated branching stems (*B*).

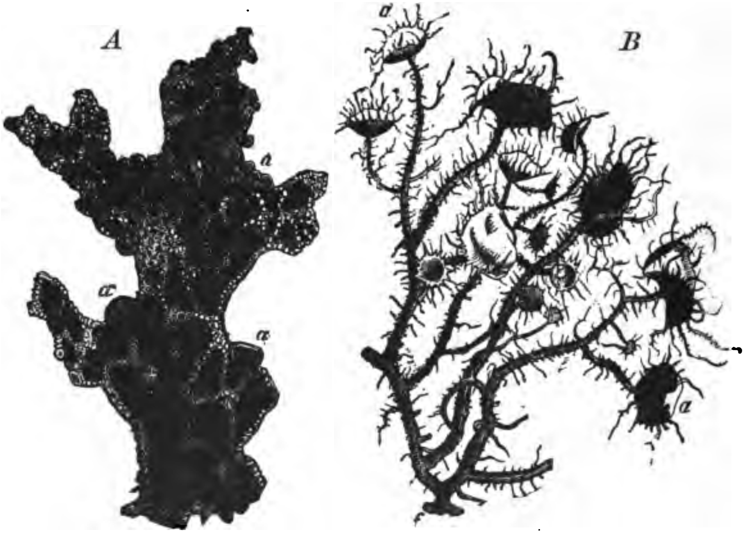

FIG. 90.—*A*, a flat-growing (foliaceous) Lichen (Sticta pulmonaria); *B*, a stemmed (fruticose) Lichen (Usnea barbata); *a*, *a*, fruit-discs (apothecia). Natural size.

350. The plant-body of a lichen is composed of jointed, branching, colorless filaments similar to those in the preceding orders. They obtain their nourishment from little green protophytes, to which they attach themselves parasi-

tically. These protophytes, which live in the midst of the moist tissues of the lichens, were until recently supposed to be parts of the lichen itself, and were called gonidia, a term which it is still convenient to use. A few lichens are parasitic in this way upon plants a little higher than protophytes.

351. The spores of lichens are produced in sacs, which are either in discs (similar to those of Cup-fungi) or in cavities (similar to those of the Black Fungi). In many common species the spore-bearing discs (called *apothecia*) are large and readily seen (Fig. 90, *A* and *B*), while in others they are small and not easily made out. In other species the spore-sacs are im-

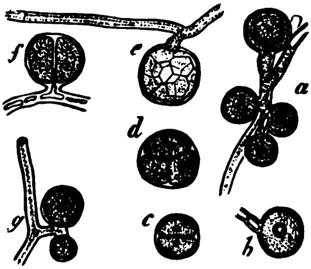

FIG. 91.

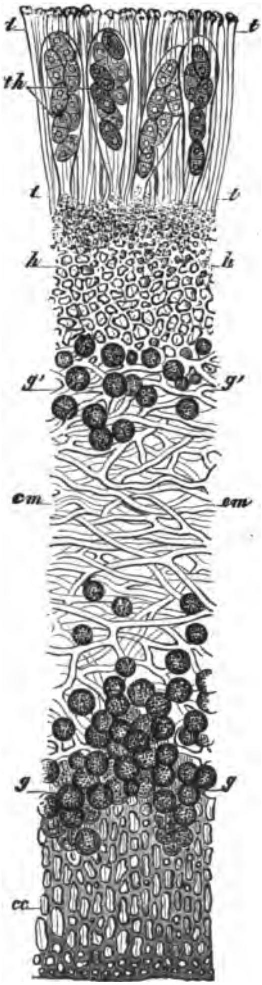

FIG. 92.

FIG. 91.—Gonidia of different Lichens, showing attachment of the parasitic filaments: several are dividing. All highly magnified.

FIG. 92.—A vertical section of a common Lichen (Physcia stellaris) through a fruit-disc, showing spore-sacs at *th*, intermingled with slender filaments (paraphyses), *t*; gonidia at *g*, *g'*; *cm*, the interlacing branching filaments, becoming harder and denser at *cc* and *h*. Much magnified.

mersed in cavities which show only as blackish lines or dots on the surface of the lichen-body.

352. The spores germinate by sending out one or more tubes which develop directly into the ordinary filaments of the lichen-body. Experiments have shown that these filaments will not grow for any great length of time unless they can come into contact with a protophyte of the proper species to which they can become attached. The lichen-filaments then grow rapidly and surround the protophytes, and in the moist tissues thus formed the latter find protection and ample opportunity for growing. There is thus an association between these plants which is mutually beneficial. The lichen lives parasitically upon the protophytes, to which it in return furnishes shelter and moisture.

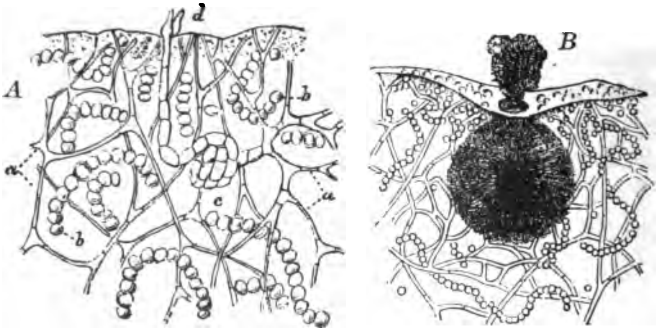

FIG. 93.—Sections of gelatinous Lichens (Collema), showing (in *A*) a carpogone, *c*, with its projection, *d*, and (in *B*) a cavity (spermogone) emitting sperm-cells (spermatia). The gonidia here (*b*, *b*) are species of Nostoc. Highly magnified.

353. We know very little as to the sexual organs of lichens. A few years ago Stahl discovered them in Collema, a low form of gelatinous lichens. The carpogone is a tightly coiled spiral filament, which sends up a prolongation to the surface (Fig. 93, *A*, *c*, *d*). Fertilization takes

place by means of minute cells (sperm-cells, or *spermatia*), which are produced in countless numbers in cavities (*spermogones*) in the lichen-body. The sperm-cells come in contact with the projecting filament (*trichogyne*), doubtless by means of winds, the result of which is the rapid upward growth of filaments which ultimately produce spore-sacs and spores in discs, as above described.

Practical Studies.—(*a*) Collect fruiting specimens of the common fruticose lichen shown in Fig. 90, *B*, which grows upon branches of trees in forests. Make thin cross-sections of the stem, mount in alcohol, afterwards adding dilute potassic hydrate. Study the filaments, and their relation to the gonidia. Isolate some of the gonidia by tapping on the cover-glass, and note their resemblance to Green Slime.

(*b*) Make thin vertical sections through one of the fruiting discs, mount as above, and study spore-sacs, spores, and paraphyses.

(*c*) Collect some of the small, flat, many-lobed lichens which grow on the bark of apple-, maple-, and oak-trees, and having small blackish fruit-discs. Make careful sections of the plant-body through the fruit-discs, and study the whole structure, spores, spore-sacs, paraphyses, filaments, and gonidia. (Compare with Fig. 92.) Here also the gonidia closely resemble Green Slime.

354. **The Rusts** (*Order Uredineæ*) are minute parasitic plants, which grow in the tissues of higher plants. Their life-history is only imperfectly known; nothing as yet being known as to their sexual organs, if indeed they have any.

355. The common Wheat-rust (Puccinia graminis) may be taken as an illustration of the order. It is common wherever wheat is grown, and often greatly injures and sometimes entirely destroys the crop. Its round of life shows four well-marked stages, as follows: (I) In the spring clusters of minute yellowish cups break through the tissues of the leaves of the Barberry. These cups are at first rounded masses of conidia which develop on the internal

parasite, and at length burst through the epidermis (Fig. 94, *A* and *I*). The conidia quickly drop out and are carried away by the winds. This stage is known as the cluster-cup stage.

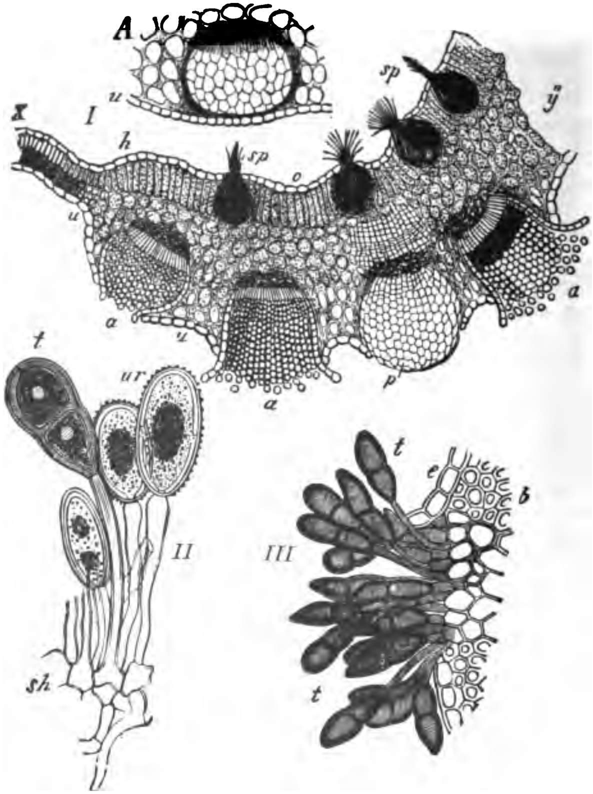

FIG. 94.—Wheat-rust (Puccinia graminis). *I*, a cross-section of a Barberry-leaf through a mass of Cluster-cups; *a*, *a*, *a*, cups opened and shedding their conidia; *p*, and *A*, above, cups not yet opened; *sp*, *sp*, spermogones which produce spermatia, whose function is not known. *II*, three Red-rust spores, *ur*, on stalks; *t*, a Black-rust spore. *III*, a mass of Black-rust spores bursting through the epidermis, *e*, of a leaf. All highly magnified.

356. (II) The conidia falling upon a wheat-leaf germinate there and penetrate its tissues, sending parasitic filaments into the cells. After a few days, if the weather has been favorable, the parasite has grown sufficiently to begin the formation of large reddish spores (stylospores) just be-

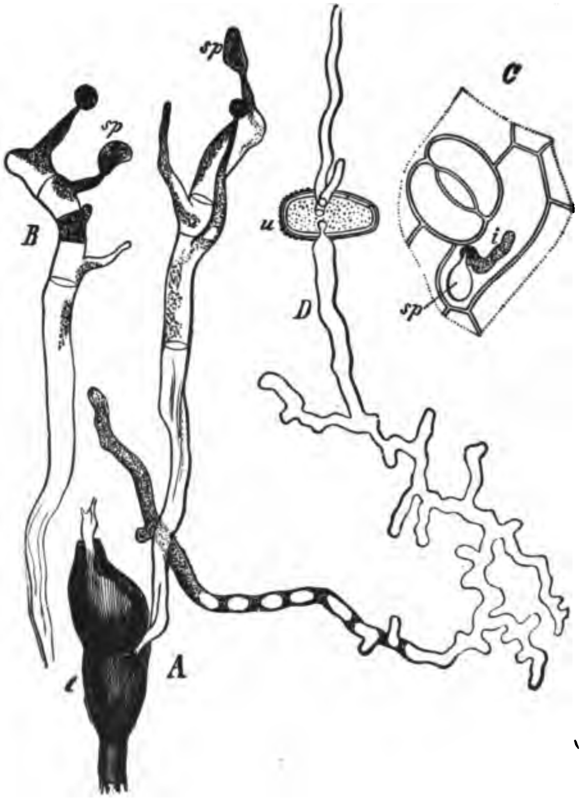

FIG. 95.—Wheat-rust. *A* and *B*, a Black-rust spore germinating, and producing sporids, *sp*; *C*, fragment of a Barberry-leaf with a sporid, *sp*, germinating and penetrating the epidermis; *D*, showing manner of germination of Red-rust spore. All highly magnified.

neath the epidermis, which is soon ruptured, exposing the spores (Fig. 94, II) in reddish lines or spots upon the leaves and stems. This is the Red-rust stage, so common before wheat-harvest. These red spores fall easily, and quickly germinate, producing more Red-rust (Fig. 95, *D*), and so rapidly increasing the parasite.

357. (III) Somewhat later in the season the same parasitic filaments which have been producing Red-rust spores begin to produce lines or spots of dark-colored, thick-walled, two-celled bodies (teleutospores), the so-called spores of the Black-rust (Fig. 94, *III*). Being thick-walled, they endure the winter without injury, and when spring comes (IV) they germinate on the rotting straw and produce several minute spores, called sporids (Fig. 95, *A* and *B*). This is the fourth and last stage of the rust. The sporids fall upon Barberry-leaves and germinate (Fig. 95, *C*), giving rise to cluster-cups again.

These stages are so different in appearance that for a long time they were regarded as distinct plants, and received different names. Thus the first stage was classified as a species of Æcidium, the second as a species of Uredó, and the third as a Puccinia. We still preserve these names by sometimes calling the spores of the first æcidiospores, and of the second uredospores, while the third name is retained as the scientific name of the genus.

The sporids cannot ordinarily produce rust directly upon wheat, probably because of the toughness of the epidermis; but it has recently been discovered that when sporids germinate upon very young leaves of wheat-seedlings, they penetrate the epidermis and then soon give rise to a red-rust stage. In such cases the cluster-cup stage is omitted. This is no doubt the mode of propagation of rust on the spring wheat so largely grown in the Mississippi Valley, and also upon oats and barley (sown in the spring), which are affected by the same species.

There are many kinds of rusts, distinguished mainly by their teleutospores, which are one-celled (Uromyces and Melampsora), two-celled (Puccinia and Gymnosporangium), or many-celled (Phragmidium). In many species the round of life is like that in Wheat-rust, but in others there appears to be a constant omission of certain stages. Moreover, in many species all the stages develop upon the same host-plant.

A teleutospore is here regarded as one or more spores contained in a thin-walled and tightly fitting spore-sac. It is therefore to be compared with the spore sacs of the previous orders (Figs. 88, 89, 92), and its simplicity is to be regarded as due to the excessive parasitism of the rusts. The Black-rust stage is thus a degraded spore-fruit, in which the spore-sacs are not compacted into a well-defined fruit-like body.

Practical Studies.—(*a*) Collect specimens of cluster-cups (from barberry, buttercups, or evening primrose, etc.); examine first under a low power without making sections. Note the cups filled with yellowish or orange conidia (æcidiospores). Note spermogones (minute dark spots) generally on the opposite side of the leaf.

(*b*) Make very thin cross-sections through a mass of cups so as to obtain vertical sections of the cups and the spermogones. (Compare with Fig. 94, *A* and *I*.)

(*c*) In June and July collect leaves of wheat, oats, or barley, bearing lines or spots of Red-rust. First examine a few of the spores mounted in alcohol, with the subsequent addition of a little potassic hydrate. Then make very thin cross-sections through a rust-spot, and mount as before, so as to see parasitic filaments in the leaf, bearing the Red-rust spores upon little stalks. (Compare with Fig. 94, *II*, *ur.*)

(*d*) In July, August, or September collect stems of wheat, oats, or barley bearing lines or spots of Black-rust. Study the spores as above, and afterwards make sections of the leaf also (Fig. 94, *III*).

(*e*) In early spring collect and examine the Black-rust on wet stems of rotting straw. Look for germinating teleutospores and sporids (Fig. 95, *A* and *B*).

(*f*) Examine microscopically the gelatinous prolongations on "cedar-apples," and observe the teleutospores, which resemble those of Wheat-rust. "Cedar-apples," which are common in the spring on Red-cedar twigs, are in reality species of rust. Their cluster-cups occur on apple-leaves.

358. **The Smuts** (*Order Ustilagineæ*). The plants which compose this order are all parasites living in the tissues of flowering plants. Like the Rusts, they send their parasitic threads through the tissues of their hosts, and afterwards

produce spores in great abundance, which burst through the epidermis. There is a still greater simplicity of structure in the plants of the present order than in the **Rusts**, probably due to a greater degradation through excessive parasitism.

359. The parasitic threads of the Smuts are well defined, and consist of thick-walled, jointed, and branching filaments, which are generally of very irregular shape. They grow in the intercellular spaces and cell-cavities of their hosts, and send out suckers (*haustoria*), which penetrate the adjacent cells much as in the Mildews. The parasite generally begins its growth when the host-plant is quite young, and grows with it, spreading into its branches as they form, until it reaches the place of spore-formation. In perennial plants the parasite is perennial, reappearing year after year upon the same stems, or upon the new stems grown from the same roots; in annuals it must obtain a foothold in the young plants as they grow in the spring.

360. The life-history of the Smuts has not yet been completely made out. Two kinds of spores have been observed in certain species, but neither the sexual organs (if any exist) nor the mode of entrance of any of the species into their hosts has yet been discovered.

361. The Smut of Indian corn (Ustilago maidis) is very common in autumn. The parasitic filaments are found in various parts of the host, and at last those which reach the young kernels become semi-gelatinous and form spores internally. There is much crowding and distortion of these spore-bearing filaments, but here and there their resemblance to spore-sacs is quite evident (Fig. 96). When the spores are ripe, the gelatinous walls of the spore-sacs dis-

solve and, the watery portions evaporating, leave a dusty mass of black spores.

The spores germinate by sending out a short filament much as in the wheat-rust (Fig. 95, *A* and *B*), upon which minute sporids are formed. The subsequent history of the sporids is not known.

362. Other Smuts, as Grain-smut or Black Blast (Ustilago segetum) of wheat, oats, and barley, and the Bunt or Stinking-smut (Tilletia tritici) of wheat have a structure and mode of development closely resembling the foregoing.

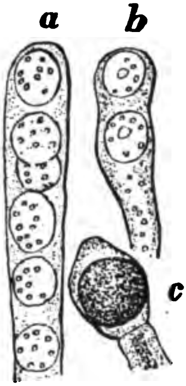

FIG. 96. — Ends of three spore-bearing filaments (spore-sacs?) of Indian-corn Smut, showing, *a*, *b*, young spores; *c*, a spore nearly ripe. Magnified 1800 times.

Comparing the spores of the Smuts with those of the preceding orders, we here consider them as sac-spores (ascospores), and the mass of tissues in which they are produced, as a degraded spore-fruit. The orderly arrangement of spore-sacs so evident in the Cup-fungi is less marked in the more parasitic Black Fungi; it is scarcely noticeable in the Rusts, while in the Smuts it has entirely disappeared. As the parasitism increases the structural degradation also increases.

Practical Studies.—(*a*) Collect several smutted ears of Indian corn. Mount a little of the black internal mass in water and observe the spores.

(*b*) Make very thin slices of young fresh specimens and examine for parasitic and spore-bearing filaments. The outer tissues of the distorted kernels are generally best.

(*c*) Make similar studies of the Grain-smut, which may be readily collected in June or a few days after the "heading" of the grain (wheat, oats, or barley).

CLASS IV. BASIDIOMYCETES (*the Puff-balls and Toadstools*).

363. The plants of this class are among the largest and finest of the fungi. They are mostly saprophytes whose

abundant vegetative filaments (*mycelium*) ramify through the nourishing substance, and afterwards give rise to the spore-fruit. The spores are produced upon slender outgrowths from the ends of enlarged cells (*basidia*), usually arranged parallel to each other so as to form a spore-bearing surface (*hymenium*), which may be external (in Toadstools) or internal (in Puff-balls). Two orders may be readily separated in this class, the Gasteromycetes and the Hymenomycetes.

364. **The Puff-Balls** (*Order Gasteromycetes*).—The plants of this order are saprophytes, whose spore-fruits are often of large size and usually more or less globular in form. The spores are always borne in the interior of more or less regular cavities, and from these they escape by the drying and rupture of the surrounding tissues.

365. The vegetative filaments of Puff-balls penetrate the substance of decaying wood, and the soil filled with decaying organic matter. They are colorless and jointed, and usually aggregate themselves into cylindrical root-like masses. After an extended vegetative period, the filaments produce upon their root-like portions small rounded bodies, the young spore-fruits, which increase rapidly in size and assume the forms characteristic of the different genera.

366. No sexual organs have yet been discovered, but analogy points to their probable existence upon the vegetative filaments just previous to the first appearance of the spore-fruits. The spore-fruits are composed of interlaced filaments loosely arranged in the interior, and an external more compact limitary tissue forming a rind (*peridium*).

367. The Puff-balls proper belong to the genus Lycoperdon, of which there are a good many species, the most

striking being the Giant Puff-ball (L. giganteum), whose spore-fruit sometimes is 30 cm. or more (one foot) in diameter. The proper plant, that is, the vegetative portion, lives underground, obtaining its food from decaying vegetable matter. The great ball is a spore-fruit composed of innumerable filaments whose swollen extremities (basidia) bear spores (basidiospores).

368. There are other genera, as the Earth-stars (Geaster), whose outer coat splits into a star-shaped form, the curious little Bird's-nest Fungus (Crucibulum and Cyathus, Fig. 97), fetid Stink-horn (Phallus), etc.

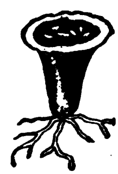

FIG. 97.—Bird's-nest Fungus (Cyathus vernicosus). Natural size.

Practical Studies.—(*a*) Collect specimens of puff-balls in various stages of growth. Make very thin sections of the young spore-fruit, and look for the cavities lined with spore-bearing cells (basidia).

(*b*) Mount in alcohol some of the dust which escapes from a dry puff-ball. Examine with a high power, and note the spores and fragments of broken-up filaments.

(*c*) Dig up the earth under a cluster of young puff-balls, and observe the vegetative filaments. Examine some of these filaments under the microscope.

369. **The Toadstools** (*Order Hymenomycetes*).—These plants are doubtless to be regarded as the highest of the chlorophyll-less Carpophytes. They are not only of considerable size (ranging from one to twenty centimetres, or more, in height), but their structural complexity is so much greater than that of the other orders that they must be regarded as the highest of the fungi. Like the Puff-balls, they produce an abundance of vegetative filaments (mycelium) underground or in the substance of decaying wood. These filaments are loosely interwoven, becoming in some cases densely felted into tough masses or compacted into

root-like forms (Fig. 98, *A*, *m*). Sooner or later these underground filaments produce the spore-fruits, which are mostly umbrella-shaped, as in common Toadstools and Mushrooms, or of various more or less irregular shapes, as in the Ear-fungi, Club-fungi, etc.

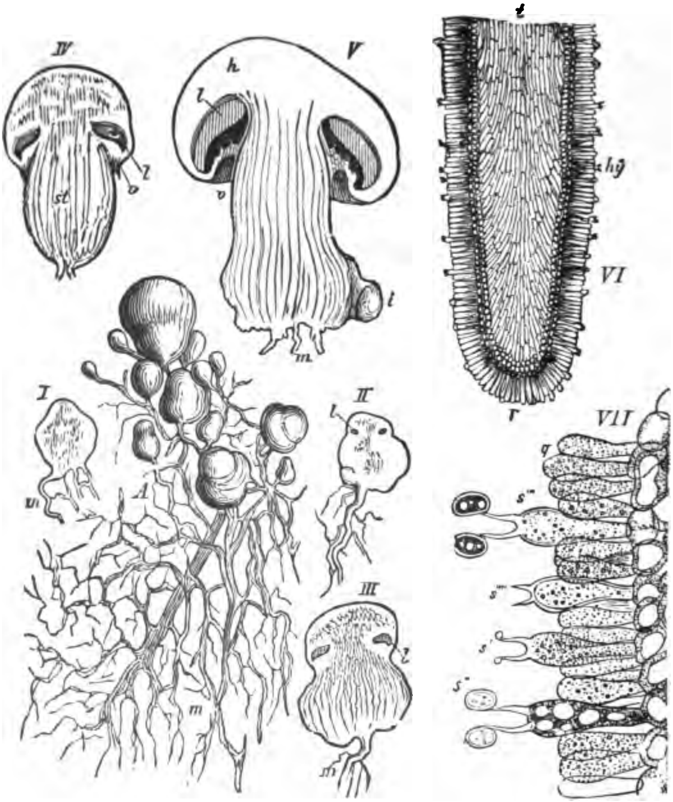

FIG. 98.—Development and structure of a Toadstool. *A*, vegetative filaments producing young spore-fruits; *I*, *II*, *III*, *IV*, *V*, sections of successive stages of spore-fruits, from very young to maturity; *l*, the gills; *v*, veil; *VI*, magnified section of a gill, showing layer of spore-bearing cells, *hy*; *VII*, greatly magnified section of part of a gill, showing layer of spore-bearing cells, with spores of different ages.

370. The Mushroom (Agaricus campestris) so commonly cultivated may be taken to illustrate the mode of development of the Toadstools. The vegetative filaments compose the so-called "spawn" which grows through the decaying matter from which it derives its nourishment. Upon this at length little rounded masses of filaments arise, which become larger and larger and gradually assume the size and shape of the mature spore-fruit, the Mushroom of the markets.

371. At maturity the spore-fruit of the Mushroom consists of a short thick stalk, bearing an expanded umbrella-shaped cap, beneath which are many thin radiating plates, the gills. Each gill is a mass of filaments whose enlarged end-cells (basidia) come to, and completely cover, both of its surfaces (Fig. 98, *VI* and *VII*). The basidia produce spores in the usual manner for plants of this class, that is, upon slender stalks.

372. In the Pore-fungi (Polyporus) the spore-bearing cells line the sides of pores; in the Prickly Fungi (Hydnum) they cover the surface of spines; while in the Ear-fungi (Stereum, etc.) they form a smooth surface.

373. But little is known as to the sexual organs. Several botanists have described such supposed organs upon the vegetative filaments before the formation of the spore-fruit, but there are still some doubts as to the correctness of the observations.

374. The vegetative filaments (mycelium) of some species of this order (as Polyporus fomentarius, etc.) often form thick, tough, whitish masses of considerable extent in trees and logs, and constitute the Amadou, or German tinder of the shops.

375. We know but little as to the germination of the

spores and the subsequent development of the vegetative filaments.

Practical Studies.—(*a*) Collect a few toadstools in various stages of development, securing at the same time some of the subterranean vegetative filaments. Note the appearance of the young spore-fruits, and how they develop into the mature toadstool.

(*b*) Select a mature (but not old) spore-fruit with dark-colored spores, cut away the stem, and place the top (pileus) on a sheet of white paper, with the gills down. In a few hours many spores will be found to have dropped from the gills upon the paper.

(*c*) Examine the minute structure of various parts of the spore-fruit and the vegetative filaments, and observe that they are composed of rows of cylindrical colorless cells joined end to end.

(*d*) Make very thin cross-sections of several of the gills and carefully mount in water or alcohol. Note the layer of spore-bearing cells (hymenium), with spores borne upon little stalks, as in Fig. 98, *VI* and *VII*.

CLASS V. CHARACEÆ (*the Stoneworts*).

376. The plants of this class are small green aquatics with jointed stems bearing whorls of leaves (Fig. 99). Both stems and leaves are very simple, being often no more than a row of cells, but sometimes a cylindrical mass of cells. The sexual organs occur upon the leaves. They consist of an ovoid carpogone and a globular antherid, which are barely visible to the naked eye.

377. The carpogone (Fig. 100, *s*) is a single cell, as in Coleochæte (p. 150), which soon becomes covered by the growth of a layer of cells from below. This covering, which here develops *before* fertilization, is homologous with the protective covering which in Coleochæte, Red Seaweeds, Blights, etc., forms *after* fertilization has taken place.

378. The antherids (Fig. 100, *a*) are globular many-celled bodies, in the interior of which certain cells produce an-

therozoids. Each antherozoid is a long spiral thread of protoplasm, provided with two long cilia at one end, by means of which they swim rapidly through the water.

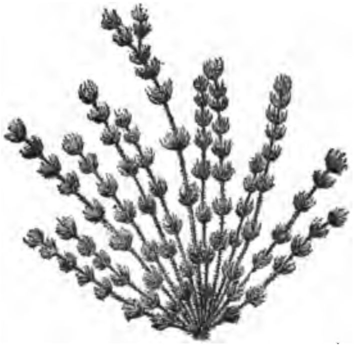

Fig. 99.—A Stonewort (Chara crinita). One half the natural size. (From Allen.)

379. Fertilization takes place by the antherozoids swimming down the opening at the top of the covering cells (Fig. 100, *c*). The carpogone and its covering now become

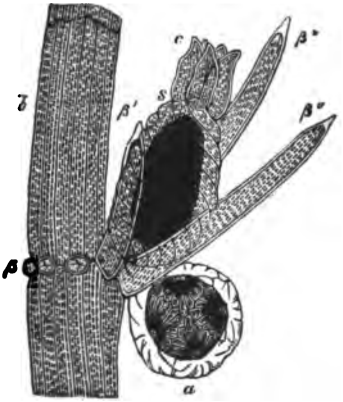

Fig. 100.—Sexual organs of a Stonewort (Chara fragilis). *a*, an antherid; *s*, spore-fruit; *c*, its crown of five cells; *b*, fragment of the leaf which bears the sexual organs; *β*, bracteoles. Magnified about 33 times.

thicker-walled and constitute the proper spore-fruit. The latter soon drops off and falls to the bottom of the water. where it remains at rest for a time.

380. The spore-fruit of the Stoneworts contains, thus, but one spore. This in germination sends out a jointed filament, which eventually gives rise to a branching plant again (Fig. 99).

381. Two orders (*Nitelleæ* and *Chareæ*) may be separated in this class. The principal genus of the first is Nitella, and of the latter Chara; each contains a dozen or more widely distributed species in this country.

Practical Studies.—(*a*) Search the sandy margins of ponds, lakes, and slow streams for Stoneworts. They are generally found in water from a few centimetres to one or two metres in depth. Preserve such specimens temporarily in water which is frequently changed, but for future use preserve in alcohol.

(*b*) Mount carefully a considerable portion of a plant, and examine its structure under a low power. Note that in some species the stem (and leaves) is composed of a row of large cells surrounded by a coat of smaller ones. Look for the rapid movement of protoplasm which is so marked in these plants.

(*c*) Mount several spore-fruits in various stages of development. Note the covering layer of spirally coiled cells surrounding the carpogone (in young specimens) or the spore (in older specimens).

(*d*) Mount several full grown antherids. Carefully crush them and look for antherozoids, which are produced in chains of cells.

CHAPTER XI.

BRANCH V. BRYOPHYTA.

THE MOSSWORTS.

382. This Branch includes plants of much greater complexity than any of the preceding. In very many cases they have distinct stems and leaves, whose tissues often show a differentiation into several varieties. In the sexual organs the cell to be fertilized (the germ-cell) is from the first enclosed in a protective layer of cells, and after fertilization it develops into a complex spore-fruit.

383. Mossworts are all chlorophyll-bearing plants, and none are parasitic or saprophytic. They are of small size, rarely exceeding ten or fifteen centimétres in height. They generally prefer moist situations upon the ground, or on the sides of trees or rocks. A few are aquatic.

384. Two classes of Bryophytes may be distinguished, as follows:

1. Mostly thalloid creeping plants with splitting spore-fruits, and having elaters........................HEPATICÆ. Liverworts.
2. Leafy stems, mostly erect, with spore-fruit opening by a lid, and having no elaters...........................MUSCI. Mosses.

CLASS I. HEPATICÆ (*the Liverworts*).

385. In the Liverworts, the plant-body is for the most part either a true thallus or a thalloid structure. When there is a differentiation into stem and leaves, in most cases the plant-body has two distinct and well-marked surfaces,

an upper and an under one, the latter bearing the root-hairs (rhizoids), by means of which the plant is fixed to the ground. In this class breathing-pores are found for the first time in the vegetable kingdom. They are of very simple structure (Fig. 101).

386. The leaves, when present, are usually in two rows (sometimes three), and are either opposite or alternate. The tissues of the plant-body show a little differentiation; the leaves, however, have no midrib or other veins, and consist of a single layer of cells. The development of the stem is always from a single apical cell, which repeatedly divides.

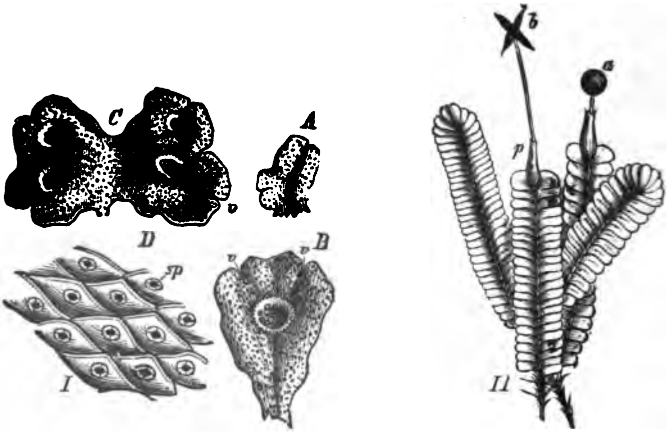

Fig. 101.—*I*, a thalloid Liverwort; *B* and *C*, showing bud-cups, natural size; *D*, enlarged to show breathing-pores. *II*, a leafy-stemmed Liverwort; *a*, unripe, and *b*, ripened and split, spore-fruit.

387. The asexual reproduction of Liverworts takes place by means of peculiar bodies, the buds (or gemmæ) so frequently to be seen in the Common Liverwort (Marchantia polymorpha). In the latter plant they are little stalked

masses of cells in small cups 4 to 6 millimetres (¼ inch) in diameter (*B* and *C*, Fig. 101). They are in reality hairs (trichomes) whose upper cells have repeatedly divided so as to form flattish masses. When these fall off they grow directly into new plants.

388. The antherids of Liverworts are more or less globular, stalked bodies (Fig. 102, *C*), usually immersed in little depressions in the plant-body. They are to be regarded as hairs (trichomes) whose end cells have become greatly increased in number. There is an outer layer of cells surrounding a great number of interior thin-walled cells, the sperm-cells, each of which contains an antherozoid.

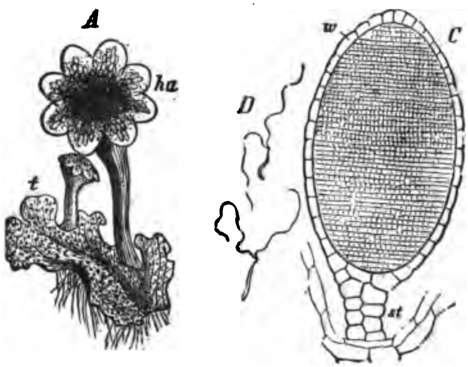

FIG. 102.—*A*, a portion of Common Liverwort (Marchantia polymorpha) with two male branches, *hu*, in which antherids are borne; *C*, an antherid, magnified; *D*, two antherozoids, greatly magnified.

In the Common Liverwort (Marchantia polymorpha) the antherids are produced in the broadly expanded discs of special branches (Fig. 102, *A*). The antherozoids are spiral threads of protoplasm, each provided with two cilia (Fig. 102, *D*).

389. The female organ of Liverworts is called an arche-

gonium, or archegone. It bears some resemblance to the corresponding organ in the Stoneworts (p. 181), and, like it, has an internal cell (the germ-cell) to be fertilized, surrounded by an envelope of protective cells (Fig. 103, *I*-*V*).

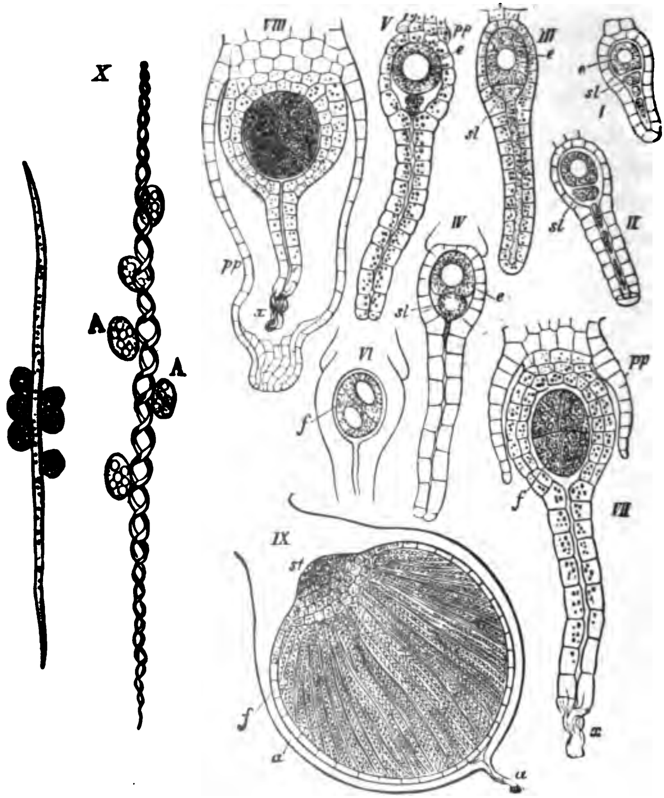

Fig. 103.—Archegones of the Common Liverwort in various stages of development, *I* to *V*; *e*, germ-cell. *VI*, fertilized germ-cell, *f*, divided once. *VII* and *VIII*, further development of germ-cell; *pp*, the perianth in various stages. *IX*, germ-cell now developed into a spore-fruit, *f*, filled with spores and elaters; *a*, the greatly distended wall of the archegone. *X*, immature and mature elaters and spores. All magnified.

The archegones of the common Liverwort are clustered upon special branches, a few centimetres in height. These branches expand into lobed discs at the top, and beneath these the archegones appear. They grow out as trichomes, and finally consist of a rounded cell (germ-cell) enclosed in a flask-shaped vessel (Fig. 103).

390. Fertilization takes place in wet weather by the antherozoids swimming to and down the open neck of the archegone. As a consequence, the germ-cell begins dividing, and finally develops into a spore-fruit containing many spores, intermixed with spiral threads called elaters. The use of the latter appears to be to aid in the dispersion of the spores (Fig. 103, *X*).

391. In most cases the spore-fruits split open to permit the escape of the spores, which soon germinate and produce a thalloid mass; this develops directly into a new plant in the lower forms, and in the higher soon begins the development of a stem and leaves.

392. There are four or five orders of Liverworts, including (1) the Crystalworts (Order Ricciaceæ), which are terrestrial or aquatic thalloid plants; (2) the Horned Liverworts (Order Anthoceroteæ), which are terrestrial thalloid plants with slender spore-fruits (Fig. 104); (3) the Liverworts proper (Order Marchantiaceæ), terrestrial thalloid plants, including the Common Liverwort (Marchantia polymorpha) and the Great Liverwort (Conocephalus conicus), both large, flat, branching plants growing in moist places about springs, brooks, ditches, etc.; (4) the Scale-mosses (Order Jungermanniaceæ, Fig. 101, *II*),

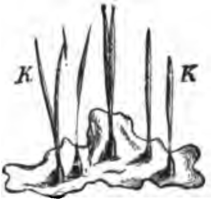

FIG. 104.—A Horned Liverwort (Anthoceros lævis), natural size, with spore-fruits, *K*, *K*, splitting open.

mostly leafy creeping plants growing on moist earth, rocks, and tree-trunks.

Practical Studies.—(*a*) Collect specimens of the Common Liverwort, which may be found in fruit in midsummer. Note that one plant produces the male branches, which have flat discs, and another produces the female branches, which have lobed discs. Note the bud-cups, with contained buds (gemmæ).

(*b*) Examine the upper surface of a plant with a low power of the microscope, and note the round breathing-pores. Next strip off some of the epidermis, mount in alcohol, and study with high power.

(*c*) Make longitudinal sections of the plant through its thickened central rib, and observe the elongated cells, which foreshadow fibro-vascular bundles.

(*d*) Make vertical sections of the male disc, mount in water, and study the antherids (Fig. 102, *C*). By repeated trials, antherozoids may be seen.

(*e*) Make similar sections of the female disc, and study archegones. By taking older specimens, the spore-fruits, spores, and elaters may be studied. For the latter, mount in alcohol and afterwards add a little potassic hydrate.

(*f*) Examine the bark of trees for small brownish Scale-mosses. Mount a bit of one in alcohol, afterwards adding potassic hydrate, and study as a specimen of a leafy Liverwort. In the spring the minute splitting spore-fruits may readily be found.

CLASS II. MUSCI (*the Mosses*).

393. The adult plant-body in this class is always a leafy stem, which is rarely bilateral. It is fixed to the soil or other support by root-hairs (rhizoids) which grow out from the sides of the stem, but there are no true roots. The leaves are usually composed of a single layer of cells, and sometimes have a midrib.

394. The tissues of the Mosses present a considerable advance upon those of the Liverworts. In the stem there is frequently a bundle of very narrow thin-walled cells, which in some species become considerably thickened. In a few cases there have been observed bundles of thin-walled

cells extending from the leaves to the bundle in the stem. It cannot be doubted, then, that the Mosses possess rudimentary fibro-vascular bundles. As in liverworts, the tissues of mosses develop from a single apical cell. Breathing-pores resembling those of the higher plants occur on the spore-fruits; they are not found upon the leaves or stems.

395. Mosses, for the most part, grow upon moist earth or rocks, or upon the sides of trees; comparatively few are aquatic. They range in size from less than a millimetre to many centimetres in length, the most common height being from two to four centimetres. They are all chlorophyll-bearing plants, and are generally of a bright-green color; occasionally, however, they are whitish or brownish.

396. The reproduction of mosses is mainly sexual, but occasionally buds are found resembling those of the liverworts. The sexual organs develop either upon the end of the stem, within flower-like rosettes of leaves, or in the axils of the leaves.

The antherids are club-shaped or globose trichomes (Fig. 105), whose interior cells (sperm-cells) produce antherozoids. The sperm-cells, when mature, escape from the antherid through a rent in its wall. Each sperm-cell contains one spirally coiled antherozoid, which, when set free, swims by means of its two long cilia (Fig. 105, *c*).

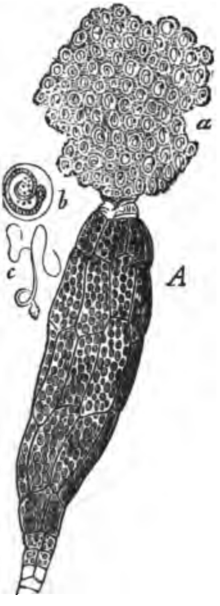

FIG. 105.—*A*, an antherid of a Moss ruptured, showing the mass of sperm-cells, *a*—magnified 350 times; *b*, a sperm-cell, magnified 800 times, showing antherozoid, which at *c* is free.

397. The archegones are elongated flask-shaped bodies with a swelling base and a long, slender neck. At maturity the neck has an open channel from its apex to the base, where there is a rounded germ-cell (Fig. 106). In some mosses the antherids and archegones are intermixed in the same "flower," but in other cases they occur upon

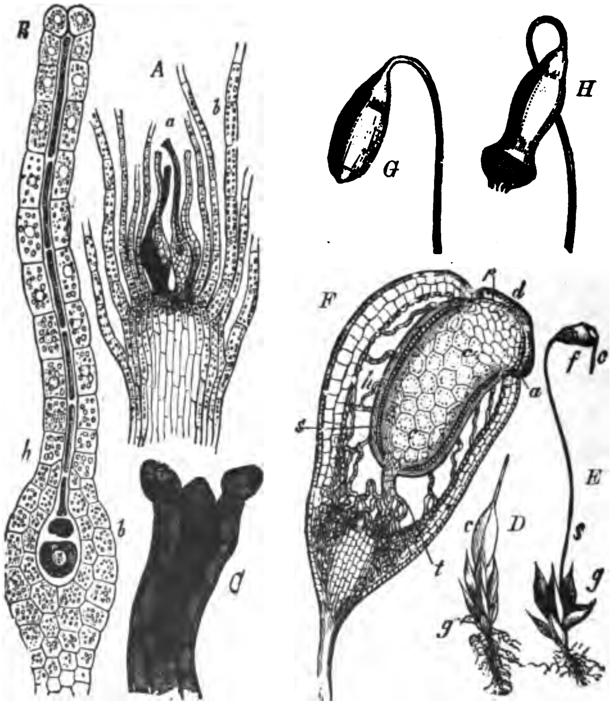

FIG. 106.—*A*, several archegones at the apex of a Moss-stem; *B*, an archegone more enlarged, showing germ-cell at *b*; *C*, apex of archegone at maturity; *D*, a Moss-plant with young spore-fruit; *E*, the same with mature spore-fruit, showing its stalk, *s*, spore-case, *f*, and the remains of the old archegone, *c* (the calyptra); *F*, vertical section of the spore-case, showing structure; *s*, the spore-bearing layer; *d*, the lid; *G*, a ripe spore-case; *H*, spore-case after the lid has fallen off, showing the teeth. All magnified.

different parts of the same plant (monœcious) or even upon different plants (diœcious).

398. The act of fertilization requires water; but as the antherozoids are so minute, a dew-drop may be sufficient. The antherozoids swim to the open neck of the archegone, down which they pass to the germ-cell. The germ-cell now begins to divide rapidly, growing upward and eventually forming the spore-fruit. In most mosses the spore-fruit is narrow and elongated below, forming a stalk which supports its upper spore-bearing part (the capsule or spore-case).

399. The spore-case, when ripe, usually opens by a lid which falls off, leaving a round opening, generally fringed with many teeth (Fig. 106, *G* and *H*). In most species, as the spore-fruit elongates it carries up the remains of the distended archegone as a little cap (calyptra) (Fig. 106, *E*, *c*).

400. The spores, which are round or angular cells containing protoplasm, chlorophyll-granules, oil-drops, etc., germinate quickly upon moist soil. Each spore protrudes a tubular filament, which develops into a conferva-like branching growth of green cells, called the protonema (Fig. 107). Upon this there finally are produced buds from which spring up the leafy stems, thus completing the round of life.

401. There are four orders of Mosses, as follows: (1) the Peat-mosses (Order Sphagnaceæ), composed of large, soft, and usually pale-colored plants, with clustered lateral branches; they inhabit bogs and swampy places, where they form dense moist cushions, often of great extent. On account of peculiarities in the structure of their leaves they are enabled to absorb and hold large quantities of water, and for this reason they are extensively used for "packing".

in the transportation of living plants. They all belong to the genus Sphagnum. (2) Order Andræaceæ, composed of a few small and rare mosses. (3) Order Phascaceæ, small mosses with but little development of a leafy stem, and a persistent protonema.

402. (4) The True Mosses (Order Bryaceæ) include the great majority of the mosses of the country. They are usually bright-green (in a few genera brownish), and in most instances live upon moist ground and rocks, or upon the bark of trees; in a comparatively small number of cases the species live in the water. They are undoubtedly the highest of the class, and show a greater differentiation of tissues than any of the preceding orders. Among the more common mosses are species of Dicranum, Fissidens, Polytrichum, including the well-known Hair-cap Moss (P. commune), Timmia, Bryum (Fig. 106, *G* and *H*), Mnium, Funaria (F. hygrometrica, Figs. 105, 106, *A* to *F*,

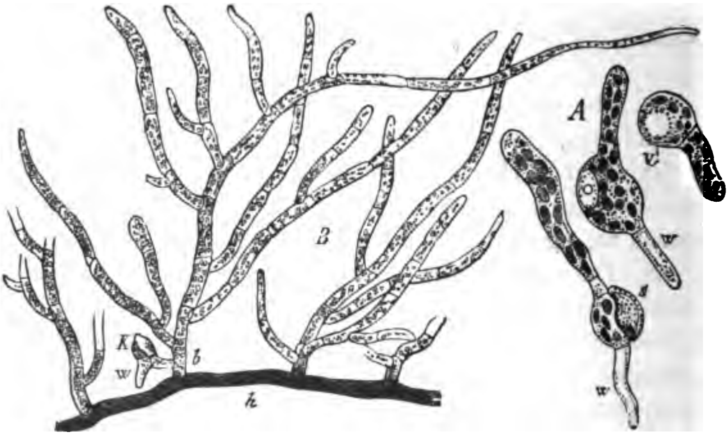

FIG. 107.—*A*, three spores of a Moss germinating; *B*, protonema of a Moss; *K*, a bud from which a leafy stem will develop. Highly magnified.

and 107); Fontinalis, large floating mosses, common in brooks and rivulets; Cylindrothecium; Climacium (C. americanum is a large tree-shaped moss); Hypnum, the bog-mosses, etc.

Practical Studies.—(*a*) Collect several kinds of mosses in fruit: some of these should be of large species. Note the brownish root-hairs, the stem and leaves, the spore-fruit composed of a slender stalk bearing a spore-case, the latter in some species covered by a membranous or hairy cap (calyptra).

(*b*) Select a broad-leaved species. Mount a single leaf in water, and examine with a low power. Note that the leaf is (generally) a single layer of cells, and that the midrib (if present) is composed of elongated cells. Make cross and longitudinal sections of stems of the larger species, and note that some of the cells are elongated and fibre-like.

(*c*) Place a spore-case under the microscope and examine with a low power, noting the lid (Fig. 106, *G*). Now remove the lid and observe the teeth (Fig. 106, *H*). The teeth may be studied still better by splitting the spore-case from base to apex and then mounting in alcohol, and afterwards adding potassic hydrate. In this specimen spores may be studied also.

(*d*) Split a young spore-case and examine the external surface of the lower part for breathing-pores.

(*e*) Collect a number of mosses not in fruit, showing at the apex of their stems little cup-shaped whorls of leaves. Make several vertical sections of one of these cups, and mount in water. Examine for antherids and archegones (Figs. 105 and 106). Antherozoids may sometimes be seen with a high power.

(*f*) The first stage (protonema) of a moss may be found by scraping off some of the greenish growth from a wall or cliff where young mosses are just springing up. By mounting some of this in water and washing away the dirt the branching green growth may generally be seen.

CHAPTER XII.

BRANCH VI. PTERIDOPHYTA.

THE FERNWORTS.

403. The Fernworts are for the most part leafy-stemmed, root-bearing plants of considerable size, whose leaves bear spores. All are chlorophyll-bearing, and they are mostly terrestrial in habit, comparatively few being aquatic.

404. Their tissues show a high degree of development. The epidermis is distinct, and contains breathing-pores similar in form and position to those of the flowering plants. The fibro-vascular bundles are generally of the concentric type, although collateral and radial bundles occur also. The bundles generally possess tracheary and sieve tissues; the former is usually well developed, but the latter not. Fibrous tissue occurs only to a limited extent within the bundles, but it is common in the stems as thick strengthening masses. These tissues generally develop from a single cell at the apex of the stem, but in the higher orders there are groups of apical cells, as in the flowering plants.

405. The round of life of a fernwort shows a curious alternation of generations. When a spore of a fernwort germinates, it produces a small, flat, green liverwort-like plant upon which sexual organs arise. This is the first stage, or sexual generation. After fertilization has taken place in the sexual organs, a leafy-stemmed, long-lived plant is produced directly. This is the second stage, or

asexual generation, and upon it the spores are produced from which new individuals of the first generation may be developed.

406. The first stage (called the prothallium) is composed throughout of a few layers of soft tissue (parenchyma) richly supplied with chlorophyll. From its under surface root-hairs grow out into the soil. The sexual organs resemble those of the liverworts, and are antherids (producing antherozoids), and archegones. They are generally produced upon the under side of the plant, and project slightly from the surface.

407. The fernworts are divisible into three classes, viz.:

1. Stems hollow, jointed; leaves small. EQUISETINÆ. Horsetails.
2. Stems solid; leaves mostly broad. FILICINÆ. Ferns.
3. Stems solid; leaves small or narrow. LYCOPODINÆ. Lycopods.

CLASS I. EQUISETINÆ (*the Horsetails*).

408. In the plants of this class the plant-body consists of a hollow elongated and jointed stem, bearing whorls of narrow united leaves, which form close sheaths (*s*, Fig. 108); the stem is grooved, and is usually rough and hard from the large amount of silica deposited in the epidermis.

409. The branches, when present, are in whorls. Both the main axis and the branches are in most cases richly supplied with chlorophyll-bearing tissue; in some of the species the stems which bear the spores are destitute of chlorophyll. All the species have underground stems, which bear roots and rudimentary sheaths, and which each year send up the vegetating and spore-bearing stems.

410. The Horsetails are perennial plants. In some species the underground portions only persist, the aerial stems

dying at the end of each year: these are called the annual stemmed species. In other species the aerial stems also persist; the latter are hence known as perennial-stemmed.

411. The epidermal cells are mostly narrow and elongated. The breathing-pores, which are present in all the chlorophyll-bearing parts of the plant, are arranged with more or less regularity in longitudinal rows; on the stem they occur in the channels between the numerous ridges.

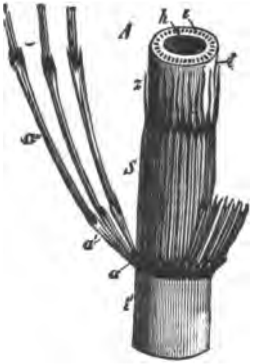

FIG. 108.

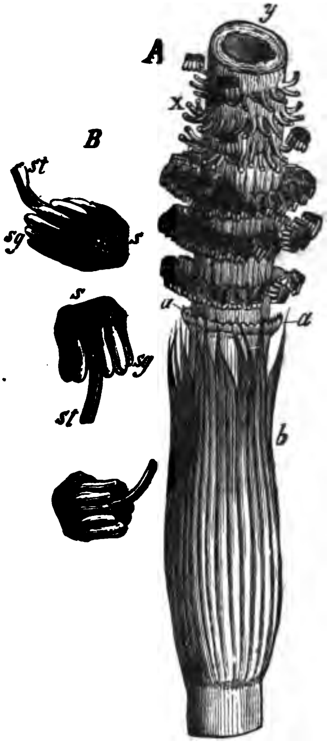

FIG. 109.

FIG. 108.—Part of a green stem of the Great Horsetail (Equisetum telmateia), showing its structure; and a whorl of united leaves, with part of a whorl of branches. Natural size.

FIG. 109.—*A*, part of an old cone of the Great Horsetail, showing three separated whorls of shield-shaped leaves; *B*, three shield-shaped leaves, slightly magnified; *st*, stalk, and *s*, expanded part of leaf; *sg*, the spore-cases.

412. The fibro-vascular bundles of the stem are disposed in a circle, and run parallel with each other from node to

node, where they join with one another. They contain tracheary, sieve, and fibrous tissues, arranged somewhat as they are in the bundles of flowering plants.

413. The spores of Horsetails are produced in cones at the summit of the stems. The cones are composed of crowded whorls of shield-shaped leaves, each of which bears upon its under surface five to ten spore-cases (Fig. 109, *B*). The spores are spherical, and at maturity the outer wall splits spirally into four narrow filaments (*elaters*) which unroll when dry, and roll up around the spore again when moistened. Their office seems to be to aid in setting the spores free from the spore-cases.

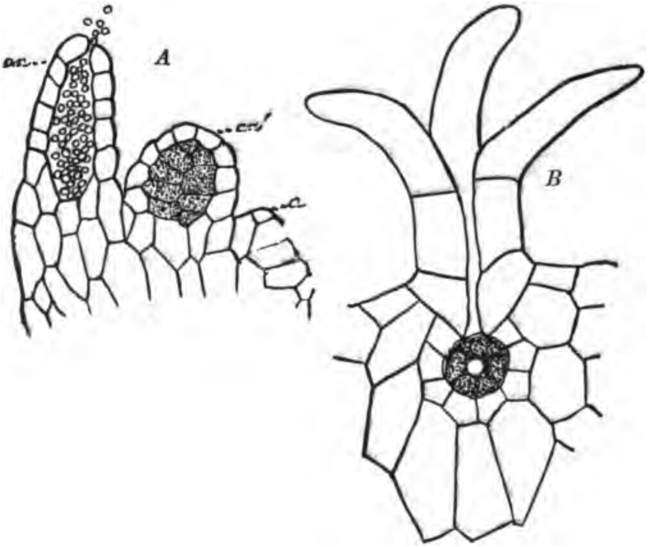

Fig. 110.—Sexual organs of Horsetail. *A*, sections of two antherids; *an'*, young, and *an*, mature, with escaping sperm-cells. *B*, section of an archegone, showing the germ-cell below. Highly magnified.

414. The spores germinate soon after falling upon water

or moist earth, enlarging and successively dividing until a flattish irregular plant (the first stage, or prothallium) a few millimetres in breadth is produced. This stage is short-lived. It bears sexual organs upon its edges or lobes; in some cases both kinds of organs are on the same plant, while very commonly they are upon separate plants.

415. The antherids consist of one or more cells, surrounded by a layer of cells. The inner cells divide internally into many sperm-cells, each of which contains a large spirally twisted antherozoid.

416. The archegones are flask-shaped organs sunken into the tissues of the plant. At maturity the neck is open down to the roundish germ-cell. Fertilization takes place in water, the antherozoids swimming by means of their many cilia to and down the neck of the archegone, where they unite with the germ-cell.

417. After fertilization the germ-cell begins to divide again and again, soon giving rise to a new plant of the second stage. The latter is at first a small and quite simple stem with minute leaves, but the successive joints become larger and larger until full size is reached. At the same time roots develop which push downwards into the soil, absorbing moisture and nutritious solutions.

This class contains but one order (Equisetaceæ) of living plants, including a single genus and twenty-five species. Among the more well known are the Common Horsetail (Equisetum arvense), which sends up short-lived, pale or brownish cone-bearing stems in spring, and profusely branching green stems in summer (E. telmateia, the Great Horsetail of Europe and our own Northwestern region, resembles, but is larger than, the Common Horsetail); the Woodland Horsetail (E. sylvaticum), whose green cone-bearing stems branch profusely after fruiting, and persist all summer; and the Scouring Rush, called also Dutch Rush (E. hiemale), with harsh green branchless stems which produce cones, and survive the winter.

In ancient geological times the Calamites and their allies constituted a distinct order (Calamarieæ) of tree-like plants ⅔ metre in thickness and ten metres in height.

Practical Studies.—(*a*) Collect in early spring a number of cone-bearing stems of the Common Horsetail. Note the joints (nodes), bearing whorls of united flat leaves, and the cone, composed of whorls of shield-shaped leaves. Split the cone and stem and note that the latter is hollow, with closed nodes.

(*b*) Carefully dissect out a single shield shaped leaf from the cone, and examine it, using a low power. Note the sac-shaped spore-cases upon the under side of the leaf. Mount some of the spores dry, using no cover-glass, and examine with the ⅛-inch objective. Breathe upon the spores *very* gently to moisten them, and notice the coiling of the elaters; observe the quick uncoiling which takes place upon the evaporation of the moisture.

(*c*) Sow a quantity of the fresh spores upon moist earth or porous pottery, covering with a bell-jar and taking every precaution to secure constant moisture. The spores will begin to germinate in a few days, when studies of successive stages of growth may be taken up. By care the mature plants of the first stage (prothallia) may be grown, and the antherids and archegones studied.

(*d*) Make very thin cross-sections of the stem of the Common Horsetail. Note the position of the fibro-vascular bundles. Now make vertical sections of the bundles and study the tissues, using high powers.

(*e*) Study the breathing-pores on the green stems of the Common Horsetail. Compare these with those of the Scouring Rush. Study also the disposition of the chlorophyll-bearing tissue in cross-sections of both stems.

(*f*) Examine underground stems of Horsetails, and compare the structure with that of the aerial stems. Make cross-sections of the roots which are attached to these underground stems.

CLASS II. FILICINÆ (*the Ferns*).

418. Here the plant-body consists of a solid stem, bearing roots and broadly expanded leaves, the latter usually long-stalked. The stems are mostly horizontal and underground, but in some cases they rise to a considerable height vertically in the air.

419. The leaves are in nearly all cases supplied with fibro-vascular bundles, which run as veins through the soft tissue; there is usually a prominent midrib, upon each side of which are small veins, which are *free* (i.e., running more or less parallel from the midrib to the margin) or *reticulated.* Some or all of the leaves at maturity bear spore-cases containing spores.

420. The ferns are all richly supplied with chlorophyll, and none are in any degree parasitic. Nearly all the species are perennial; in some cases, however, dying down to the ground at the end of the summer, the underground portions alone surviving the winter.

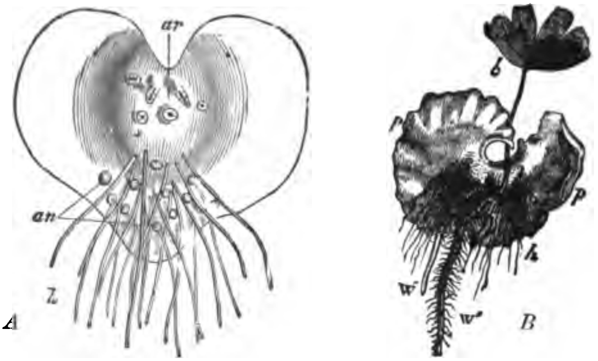

FIG. 111.—*A*, the first stage of a Fern, under side; *b*, root-hairs; *an*, antherids; *ar*, archegones. *B*, the same after fertilization, showing the growth of the fernlet; *b*, its leaf; *w'*, its first root. Magnified a few times.

421. The first stage in the ferns is frequently somewhat heart-shaped, and is generally provided with root-hairs on its under surface, by means of which it secures nourishment for its independent growth (Fig. 111, *A*). In the Pepperworts the first stage is so reduced as to be only a small outgrowth of the germinating spore.

422. The antherids and archegones resemble those of the Horsetails; however, in the highest order (Pepperworts) the antherids become greatly reduced.

423. The ferns are classified mainly upon the structure of their spore-bearing parts. Four orders may thus be separated.

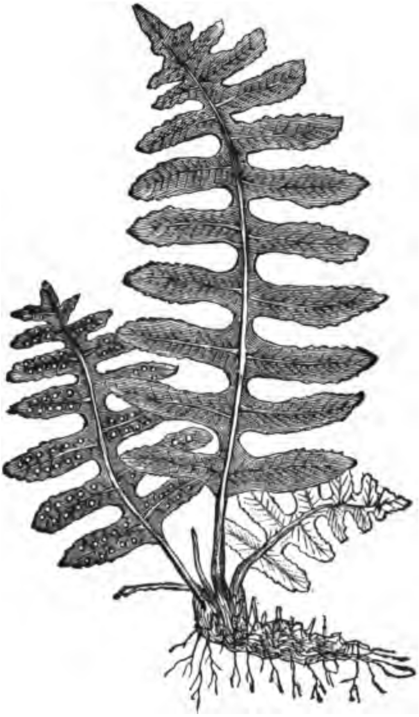

FIG. 112.—A common Fern (Polypodium vulgare) showing the underground root-bearing stem, and the leaves, one with round spore-dots on its lower surface. Natural size.

424. **The True Ferns** (*Order Filices*) include very nearly all the common fern-like plants of our woodlands and hill-

sides. They are among the most beautiful of our land-plants, and their leaves furnish examples of a gracefulness of bearing and outline scarcely excelled in the vegetable kingdom. In temperate climates ferns are herbaceous, but in the tropics many possess a perennial woody stem which bears a crown of leaves upon its summit.

425. The tissues of the True Ferns are well developed. The epidermis resembles that of the flowering plants. Complicated fibro-vascular bundles run through the stems and extend into the leaves, where they branch extensively, forming the delicate veins which are so characteristic of fern-leaves.

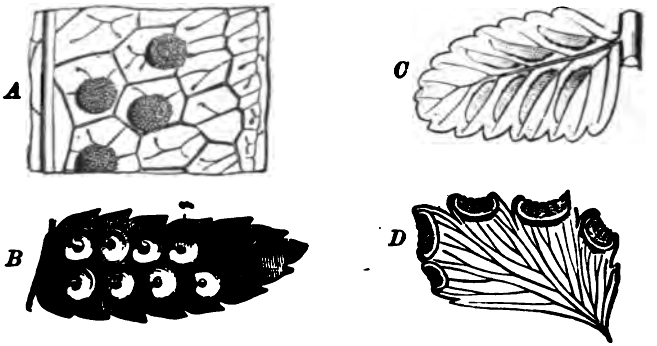

Fig. 113.—Spore-case clusters (spore-dots, or sori) of various Ferns. *A*, round and naked (Polypodium); *B*, round and covered (Aspidium); *C*, elongated and covered (Asplenium); *D*, elongated, and covered by folding of the leaf (Adiantum). All magnified. (The covering is known as the indusium.)

426. The young leaves before expanding are coiled or rolled, so that as they grow up and open they unroll from below upwards (i.e., circinately). Upon the lower surface of some of the leaves little clusters of club-shaped hairs (trichomes) grow out, generally in connection with a fibro-vascular bundle. The internal cells of the larger end of these hairs undergo subdivision, and thus give rise to a

number of spores. The hairs are thus spore-cases. In some ferns these clusters of spore-cases are naked (Fig. 113, *A*); while in others they are covered by a special outgrowth of the epidermis (Fig. 113, *B*, *C*), or by a folding of a part of the leaf (Fig. 113, *D*), etc.

427. The mature spore-case in most common ferns has a ring of thicker cells extending around it. When these become dry, they contract in such a way as to break open the spore-case and thus set the spores free.

428. The spores soon germinate, upon moist earth. The first stage thus produced is generally a little heart-shaped, flat, green plant, adhering closely to the earth by its root-hairs. After some weeks or months little "seedling" ferns may be found, with one or two minute leaves. Under favorable conditions every such fernlet will give rise to a strong and long-lived fern.

Among our common ferns are the Common Polypody (Polypodium vulgare, Fig. 112), the Golden Fern (Gymnogramme triangularis) of California, the Maidenhair of the North (Adiantum pedatum) and of the South (A. capillus-veneris), the Common Brake (Pteris aquilina), the Spleenworts (Asplenium) of many species, the Shield-ferns (Aspidium), also of many species, the curious little Walking-leaf (Camptosorus rhizophyllus), the Bladder-fern (Cystopteris fragilis), the large Ostrich-fern (Onoclea struthiopteris), the Flowering Ferns (Osmunda) of several species, and, most beautiful of all, the Climbing Fern (Lygodium palmatum) of the Appalachian region.

In the Coal Period the ferns were much more numerous than at the present. Many families which flourished then are now extinct. The ferns of that period were often tree-like and of large size.

429. **The Ringless Ferns** (*Order Marattiaceæ*) constitute an interesting transitional group, all exotics. Some are cultivated in fern-houses.

430. **The Adder-Tongues** (*Order Ophioglossaceæ*) include a few species of fern-like plants, which differ from the true

ferns mainly in the mode of development of the large ringless spore-cases, and in the leaves being straight or folded (not rolled) before expansion. The first stage is much

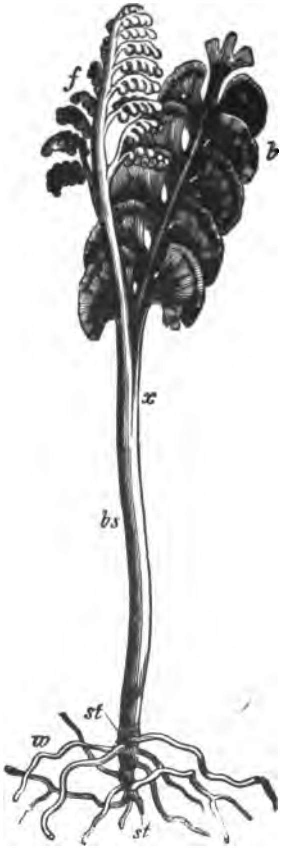

FIG. 114.

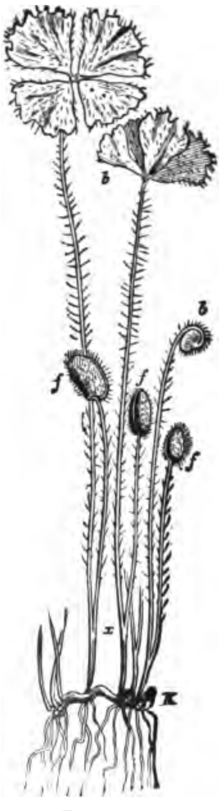

FIG. 115.

FIG. 114.—Moonwort (Botrychium lunaria), one of the Adder-tongues. *st*, the short stem bearing the divided leaf, *bs*, of which *b* is the sterile, and *f* the fertile, part.

FIG. 115.—A Pepperwort (Marsilia salvatrix, from Australia). *k*. the creeping stem, bearing the divided leaves, of which *b*, *b*. are the sterile, and *f*, *f*, the fertile, parts (the so-called fruits). One half the natural size.

smaller than it is in the true ferns, indicating a tendency towards its disappearance.

Two genera, Ophioglossum, Adder-tongues proper, and Botrychium, the Moonworts, are represented in the United States by ten or eleven species.

431. **The Pepperworts** (*Order Rhizocarpeæ*) are small aquatic or semi-aquatic plants, producing spores of two kinds, viz., small ones (microspores) which are very numerous, and large ones (macrospores) which are less numerous. The spore-cases are enclosed in rounded "fruits" or receptacles which are modified parts of leaves.

432. The small spores, upon germinating, produce a slight outgrowth of a few cells (some of which develop antherids and spiral antherozoids), which is the extent of the first stage. The large spores likewise produce a few-celled growth, which is barely large enough to burst and protrude beyond the spore-wall. Archegones are developed upon these, and from them, after fertilization, the leafy stage of the plants is produced.

A few species of Pepperworts are sparingly found in the United States. Some have four-lobed leaves, as in the genus Marsilia (Fig. 115), of which M quadrifolia occurs in New England, M. vestita and others in the Mississippi valley and westward; Pilularia, with filiform leaves, is represented by P. americana of the Southwest; it is 2 to 4 centimetres high, and grows in muddy places; Azolla, containing minute, moss-like, floating plants, is represented throughout the United States by A. caroliniana. These interesting plants, which should be sought for more than they have been hitherto, are doubtless much more common than we now consider them to be.

Practical Studies.—(*a*) Collect several different kinds of ferns, including the underground portions as well as the leaves. Study the fibro-vascular bundles, stony tissue, and fibrous tissue in the underground stem (Fig. 116).

(*b*) Examine the disposition of the small fibro-vascular bundles in the leaves, whether free or reticulated. Peel off a bit of epidermis from both surfaces, and study the breathing-pores.

(*c*) With a low power study the spore-dots, using top light only. The spore-cases may be easily seen and their attachment made out in this way, in those cases where there is no covering to the spore-dot.

(*d*) Make a vertical section through the cluster of spore-cases, and study carefully, looking for the ring of darker cells on the spore-cases.

(*e*) The first stage of ferns may often be found in plant-houses on or in flower-pots near ferns. They may be found also by carefully examining the moist earth among mosses, etc., in shady ravines. Collect a few of these of various sizes, and keep them in water in a watch-glass. Carefully wash off the dirt from the under side, and then mount in water, and examine the under surface for antherids and archegones (Fig. 111, *A*). By careful searching, young fernlets may be found still attached to the first stage (prothallium), as in Fig. 111, *B*).

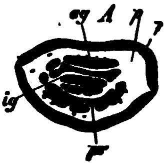

FIG. 116.—Cross-section of underground stem of a Brake (Pteris aquilina). *og*, outer ring of fibro-vascular bundles; *ig*, inner fibro-vascular bundles; *pr*, two bands of fibrous tissue (shown in black); *p*, soft tissue (parenchyma); *r*, rind of stony tissue.

(*f*) Collect specimens of Adder tongue or Moonwort, and compare the structure of the spore-bearing organs with the foregoing.

(*g*) Search the borders of lakes, ponds, and slow streams for Pepperworts. They may probably be found in every part of the country, although they have rarely been collected.

CLASS III. LYCOPODINÆ (*the Lycopods*).

433. The plant-body consists of a solid, dichotomously branched, leafy, and generally erect stem. The leaves are small, simple, sessile, and imbricated, and usually bear a considerable resemblance to those of Mosses. The roots are mostly slender and dichotomously branched.

434. The Lycopods are for the most part terrestrial perennials. They are usually of small size, rarely exceeding a height of 15 or 20 centimetres (6 or 8 inches).

435. The spores of the Lycopods are produced in spore-cases on the upper side of the leaves. In some of the

genera the spores are of one kind; while in others they are of two kinds, large ones (macrospores) and small ones (microspores).

436. The first stage (prothallium) is but little known in the genera with one kind of spore only; it appears, however, to be a thickish mass of tissue, which develops underground, and bears both kinds of sexual organs. In the genera with two kinds of spores, the macrospores produce small cellular growths, which project slightly through the ruptured spore-wall, and upon these several or many archegones are formed; the microspores produce very small, few-celled growths, each of which bears a single antherid, in which there are developed a few antherozoids.

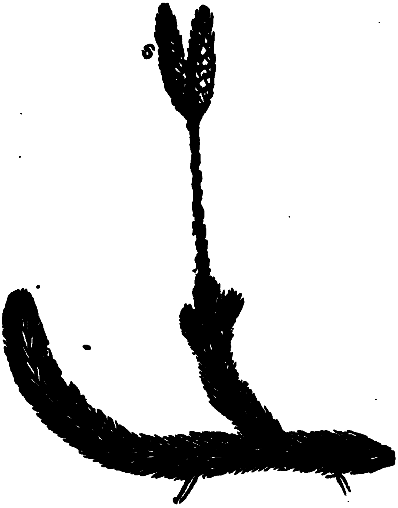

FIG. 117.—Part of a Club-moss (Lycopodium clavatum), the running. horizontal rooting stem below, with the spore-bearing cones, *s*, above. One half natural size.

There are three orders of Lycopods, viz.:

437. **The Club-Mosses** (*Order Lycopodiaceæ*) are terrestrial plants with many small, generally moss-like leaves covering the stems. The spore-bearing leaves are often crowded towards the summits of certain branches, in some cases forming well-marked cones (Fig. 117, *s*). The spores

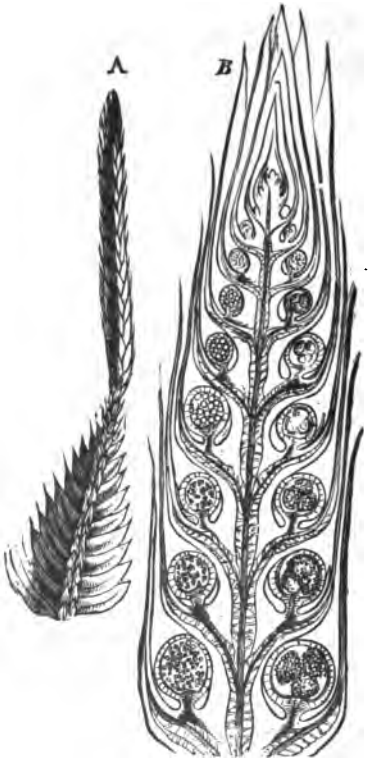

FIG. 118.—*A*, part of branch of a Little Club-moss (Selaginella inæquifolia), bearing a cone. Natural size. *B*, enlarged vertical section of a cone, showing spore-cases, with large and small spores.

are all of one kind, and are borne in roundish spore-cases, which are generally single on each leaf.

The Club-mosses are common in the Appalachian region, Canada, and northwestward, and all but one of our species belong to the genus Lycopodium. Of these may be mentioned the Common Club-mosses (L. clavatum and L. complanatum) and the Ground-pine (L. dendroideum), all extensively used in Christmas decorations.

438. **The Little Club-Mosses** (*Order Selaginellaceæ*) resemble the foregoing, but are generally smaller and more Moss-like, and have (with few exceptions) four-ranked leaves. Their spore-cases occur singly on certain more or less modified leaves, which are clustered into terminal spikes. The spores are of two kinds; the small ones, which are very numerous, are generally borne in spore-cases in the upper part of the spike, while the larger ones (macrospores) are mostly four in each spore-case in the lower part of the spike (Fig. 118).

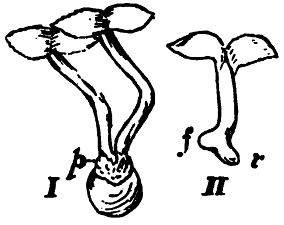

FIG. 119.—Plantlets of a Little Club-moss (Selaginella martensii), showing cotyledons. *I*, two plantlets growing from one spore; *p*, the first stage (prothallium). *II*, a plantlet separated from the spore; *r*, root; *f*, a structure called the "foot." Magnified.

439. The first stage of the Little Club-mosses is almost obliterated. When a small spore germinates, it becomes divided internally into a considerable number of cells, one of which appears to represent the first stage (prothallium), while all the rest form one large antherid, each cell of which produces an antherozoid.

440. The large spore likewise produces a very small growth, which in this case, however, protrudes a little from the ruptured spore-wall. Upon this several archegones de-

velop. After fertilization the germ-cell gives rise directly to a leafy plant, which emerges from the spore-wall in a way to remind one very forcibly of the growth of a plantlet from a seed. This resemblance is made greater by the likeness the first leaves bear to cotyledons (Fig. 119).

But one genus, Selaginella, is known in this order. It contains about three hundred species, most of which are tropical. Two only (viz., S. rupestris and S. apus) are common throughout the United States, although five others are indigenous. Several exotic species are commonly cultivated in plant-houses.

441. The **Quillworts** (*Order Isoëtaceæ*) are small grass-like plants, with narrow leaves growing from short, thick, tuber-like stems. They grow in water or muddy places.

442. Their spores, which are of two kinds, are produced in spore-cases on the upper surfaces of the leaf-bases. In their germination and development of the sexual organs they resemble the plants of the previous order.

The Quillworts are all of one genus, Isoëtes, of which there are in the United States fourteen species.

Fossil Lycopods.—Two orders of Lycopods once existed, containing large trees, which appear to have been very abundant. The Lepidodendrids (Order Lepidodendraceæ were a metre (3 to 4 feet) thick and 15 to 20 metres (45 to 60 feet) high, and seem to have had the general appearance of the Club-mosses. The Sigillarids (Order Sigillariaceæ) appear to have been trees 30 or more metres (100 feet) in height and 1½ metres (4 or 5 feet) in diameter. Both produced two kinds of spores, showing their relationship to the Little Club-mosses and the Quillworts. Although very abundant in the Coal Period, they have long since become entirely extinct.

Practical Studies.—(*a*) Secure a few fresh or alcoholic specimens of various kinds of Lycopods in fruit. The Little Club-mosses may be readily obtained in plant-houses. Make cross-sections of the stems and study the fibro-vascular bundles, which in Lycopodium are imbedded in a thick mass of fibrous tissue. Examine the leaves, noting the small fibro-vascular bundle in the midrib. Study the epidermis, which contains numerous breathing-pores.

(*b*) Carefully dissect out from the fruiting cone of a Little Club-moss several spore-cases, the lower ones with four large spores, the upper with many small spores. Examine in like manner a cone of Lycopodium, in which but one kind of spore will be found.

(*c*) Search the borders of lakes, ponds, ditches, and slow streams for Quillworts, which may be at once distinguished from grasses, rushes, etc., by the spore-cases on the bases of the leaves. Although they are rarely collected, they may doubtless be found in almost every locality in the United States.

CHAPTER XIII.

BRANCH VII. PHANEROGAMIA.

THE FLOWERING PLANTS.

443. In this great group we find the highest development of the plant-body, its tissues, and organs of reproduction. They are the most complex in structure, and most difficult to fully understand, of all the plants in the vegetable kingdom.

444. The plant-body is composed of roots, stems, and leaves, generally well developed. Frequently these members of the plant-body are more or less branched, giving rise to extensive branching root-systems, branching stems, and branching leaves. Hairs (trichomes) of various forms may occur upon all parts of the plant.

445. By far the greater number of flowering plants are chlorophyll-bearing, comparatively few only being parasitic or saprophytic. They range from minute plants one or two centimetres in height, and living but a few days or weeks, to enormous trees, which continue to grow for many hundred years, and attain a height of a hundred metres or more.

446. The tissues are generally well developed in flowering plants. The epidermis, which is copiously supplied with breathing-pores, consists of one or (rarely) more layers of cells, whose external walls are generally somewhat thickened, and whose cell-contents rarely contain chlorophyll.

447. The fibro-vascular bundles are of the collateral form, the only exception being the first-formed bundle in the root, which is of the radial type. The bundles are symmetrically arranged in the stem, through which they run nearly parallel to each other, and extend into the leaves; a few, however, have no connection with the leaves.

448. All the kinds of tissues, with the exception of thick-angled tissue, may occur in the bundles; but they are mainly made up of tracheary, sieve, and fibrous tissues. In the larger perennials, as the trees, the great mass of tissue in the woody stems is principally made up of the tracheary and fibrous tissues of the fibro-vascular bundles. In succulent plants, especially those growing in water, the bundles are usually smaller and more simple, being sometimes reduced to a thread of tracheary or sieve tissue.

449. Of the remaining tissues, soft tissue, in its various forms, is by far the most common. The hypodermal portions are frequently composed of thick-angled or stony tissue. Milk-tissue is common in certain orders.

450. The organs of reproduction in all flowering plants are modifications of the type found in the higher Fernworts. The leafy plant produces two kinds of cells, answering to the two kinds of spores we have lately studied. Moreover, these reproductive cells are produced, as in Fernworts, upon more or less modified leaves.

451. The small reproductive cells, which are here called pollen-cells instead of spores, develop in great numbers within sac-like enlargements upon certain modified leaves. They are set free by the breaking of the sac, and then mostly fall out and are borne away by the winds, by insects, or other means.

452. The larger reproductive cells are likewise produced

within outgrowths of certain modified leaves. Only a few are produced in each outgrowth, and of these rarely more than one become fully developed. Moreover, these larger cells (here called embryo-sacs instead of spores) never become free, but always remain within the outgrowth.

453. We have seen that in the higher Fernworts the parts of the plant-body bearing the reproductive cells are considerably modified, often forming cones. In the flowering plants this modification is carried still further, giving us in the lower orders such structures as the *cones* of pines, etc., and in the higher orders the many varied and beautiful forms of *flowers*.

454. The modified leaves upon which the pollen-cells are produced are known by the name of stamens, and the sac-like enlargements (corresponding to spore-cases) are commonly called anthers. The outgrowths in which the embryo-sacs develop are known as ovules, and the leaves bearing these are the fruiting leaves, or carpophylls.

455. The embryo-sac soon undergoes a few changes, somewhat similar to but much less than those in the large spores of the Lycopods, resulting in a germ-cell similar to the germ-cell of an archegone. About this time a mass of cells, corresponding to the first stage of a Lycopod, develops in the embryo-sac. It is a belated growth; having lost nearly all its former usefulness as a supporting and nourishing tissue for the sexual organs, its development is more or less retarded.

456. Fertilization of the germ-cell takes place essentially as in plants of a lower grade. When the pollen-cell germinates, it forms in a few cases a several-celled first stage (prothallium), reminding us again of the higher Lycopods. More commonly even this feeble growth of a first stage

has not been detected. In either case the pollen-cell develops a tubular filament, sometimes of great length. If, now, such a germinating pollen-cell happens to be favorably placed near to an ovule, the pollen-tube may penetrate it and come in contact with the germ-cell. The protoplasm of the tube then unites with that of the germ-cell, and fertilization is complete.

457. The fertilized germ-cell soon begins growing and dividing, producing in a short time a many-celled body—the embryo-plant. The embryo during its growth is nourished by the surrounding cells of the first stage, here called the endosperm. While the embryo has been growing, the covering of the ovule (one or two cellular coats) becomes gradually harder and firmer; finally, the growth of the embryo stops, and the ovule containing it separates from its supporting fruit-leaf as a ripe *seed.*

458. After a longer or shorter period of rest, the little plant in the seed resumes its growth, the necessary conditions being the proper heat and moisture. It is at first quite simple, consisting of a little root and stem and a few small leaves, but with the development of each succeeding leaf it becomes more like the adult plant.

459. The flowering plants are separated into two classes, viz.:

1. Ovules on an open fruit-leaf—GYMNOSPERMÆ.
2. Ovules enclosed within a closed fruit-leaf—ANGIOSPERMÆ.

CLASS I. GYMNOSPERMÆ (*the Gymnosperms*).

460. These are plants with solid stems, which bear in most cases small, simple, narrow leaves with parallel veins. Most of them are large trees, and all are terrestrial and

chlorophyll-bearing, none being in any wise parasitic. Common examples are the pines, spruces, firs, etc.

461. The general structure of the reproductive organs may be understood from a study of those of the pines. The pollen-bearing flowers—staminate flowers, as they are

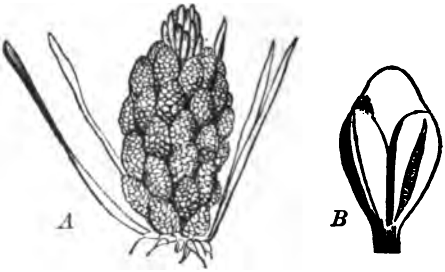

FIG. 120.—A cluster of staminate cones or flowers. *A*, of a Pine (Pinus sylvestris), with a detached stamen. Natural size. *B*, showing the two pollen-sacs. Considerably magnified.

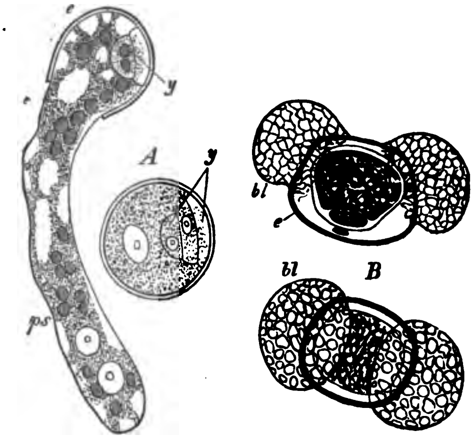

FIG. 121.—Pollen-cells of Gymnosperms. *A*, of a Cycad; *y*, rudimentary first stage (prothallium), one pollen-cell germinating. *B*, pollen-cells of a Pine, side and top views, showing bladder-like enlargements of outer cell-wall, *bl*; the rudimentary prothallium is shown here also. Much magnified.

generally called—are loose cones generally crowded into considerable clusters. Each cone consists of a stem upon which are many flattish stamens, each bearing two pollen-sacs (Fig. 120).

462. The pollen-cells are roundish, and covered by a double wall, the outer being thick and hard, and in some cases swollen out into bladder-like enlargements, apparently for the purpose of enabling the cell to be carried in the air (Fig. 121, *B*). One or more cells of the rudimentary first stage are always present (Fig. 121, *y*).

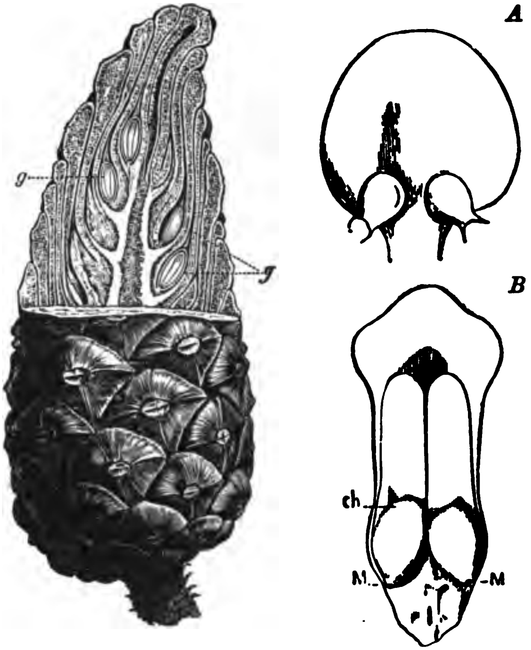

FIG. 122.—A ripe cone of a Pine, partly cut away to show the position of the seeds, *g*; *A*, a scale from a young cone, upper side showing two ovules (enlarged); *B*, the same when mature, showing two winged seeds, *ch*. Each seed-coat has a small pore, *M*, through which the first root will grow in germination.

463. The ovule-bearing flowers consist of the well-known cones which, when mature, bear the seeds (Fig. 122). The cone consists of a stem bearing many leaf-like scales closely crowded together, and upon these the ovules are produced. Each ovule has one coat which grows up from below, almost covering it; but as the ovules grow they bend down, so that the opening through the coat comes to be below (Fig. 122, *A* and *B*).

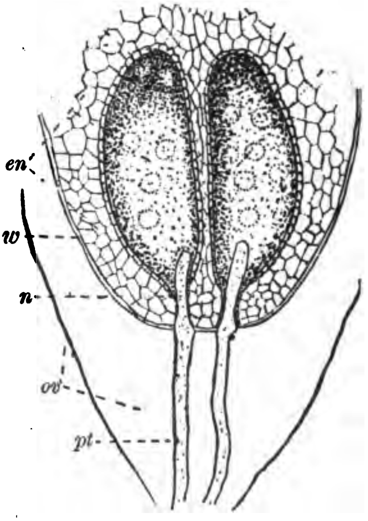

FIG. 123.—Part of a Pine-ovule. *ov*, the body of the ovule; *w*, embryo-sac filled with endosperm, *en*, which contains two large cells (rudimentary archegones); *n*, neck of archegone; *pt*, pollen-tubes growing upward into necks of archegones. Magnified 30 times.

464. The embryo-sac appears in the body of the ovule, when the cone is quite small, as an enlarged cell. It soon forms a mass of cells (the endosperm, or rudimentary first stage) within itself, and in this are developed one, two, or more rudimentary archegones, each with its germ-cell.

Thus we see that the development which takes place here inside of the ovule (which corresponds to the spore-case) is similar to that which in the Lycopods takes place only after the large spore has separated itself from the parent-plant.

465. Fertilization takes place as follows: The scales of the cone open slightly, permitting the pollen, which has been carried in the wind, to roll down to their bases where the ovules are. Here the pollen-cells germinate, and their tubes enter the opening in the ovule-coat and push through the tissues to the archegones, where the pollen-protoplasm is fused with that of the germ-cell (Fig. 123).

466. As a result of the fertilization, there is first a growth of a row of cells (called the suspensor, erroneously), upon the end of which the embryo begins to form. The root-end of the embryo is always in contact with the suspensor, so that, taking the whole embryo at maturity, the suspensor is at one end and the little leaves at the other. Moreover, the root-end of the embryo is always directed towards the opening in the ovule- or seed-coats. The embryo proper is composed of a little stem ending in a short root below and bearing a number of little leaves (cotyledons) above. The stem ends in a bud, above and within the whorl of leaves. During the growth of the embryo the ovule enlarges, and its coat becomes thicker and harder, and at last, when growth within has ceased, it separates from the parent-plant as a seed (Fig. 124, *I*).

467. In germinating, the seed first absorbs water and swells so as to burst its thick coat, the root elongates and pushes out into the soil (Fig. 124, *A*), soon sending out little branches. The leaves (cotyledons) are in contact with the endosperm, which is rich in starchy and sugary matters, which afford the plantlet food for its growth. Finally,

by the elongation of the leaves, the whole plant is pushed out of the now empty seed-coat (Fig. 124, *III*).

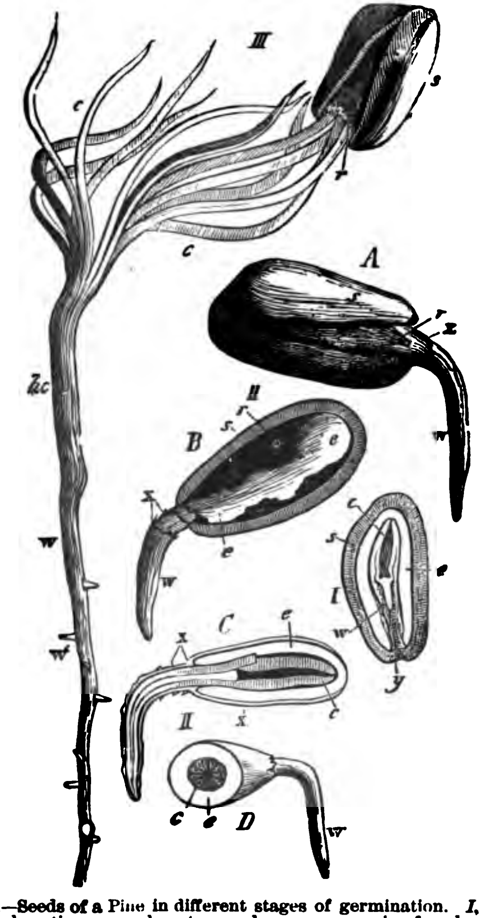

Fig. 124.—Seeds of a Pine **in different stages of germination.** ***I*, ripe seed in longitudinal section; *s*, seed-coat; *e*, endosperm; *w*, axis of embryo; *c*, leaves; *y*, opening in seed-coat. *II*, *II*, four views of the beginning of germination: *A*, external view; *B*, with half of the seed-coat removed; *C*, in longitudinal section; *D*, in transverse section; *s*, seed-coat; *e*, endosperm; *c*, leaves; *w*, root. *III*, germination completed.**

468. The tissues of the Gymnosperms are individually but little higher than those of the Fernworts, but in their arrangement they show great and important differences. The fibro-vascular bundles are of the collateral form, and are so placed in the stem that the harder and more woody side is nearer the centre of the stem, while the softer side is always nearer to the surface (Fig. 125, *A*). The inner part of the bundles is composed mostly of long, large cells, the tracheïds, which have the well-known characteristic bordered pits (Fig. 126). The outer part contains, besides other tissues, a little fibrous tissue (bast-fibres). Between these two halves of the bundles there is a thin layer of growing cells (cambium) which is continuous with a layer between the bundles (Fig. 125, *A* and *B*). At this stage the stem is composed of an inner

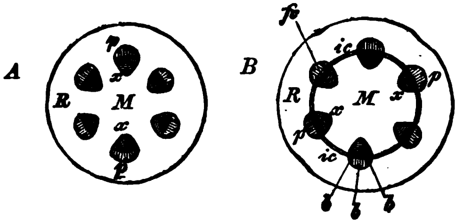

FIG. 125.—Diagrammatic cross-sections of stems, showing the fibro-vascular bundles, *fc*, of which *x* is the woody side and *p* the softer or bark side; *b*, *b*, *b*, bast-fibres; *R*, *M*, the fundamental tissues of the stem, of which *R* (the rind) is the cortical and *M* the medullary portion, or pith; *ic*, a belt of cambium which extends from bundle to bundle.

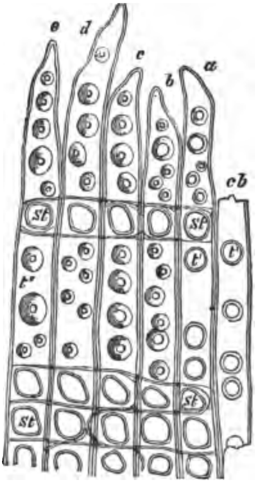

FIG. 126.—Longitudinal section of wood of a Pine (Pinus sylvestris). Bordered pits, *t'*, *t'*, *t''*; *a–e*, parts of six tracheïds; *sl*, large pits, where medullary rays touch tracheïds. Magnified 325 times.

mass of cells, the pith (*M*), and an outer, the rind, or cortex (*R*), connected with one another by the broad rays between the bundles (Fig. 125).

469. As the stem grows older, the cambium of the bundles keeps on forming tissues similar to those already found in the bundle; in other words, the woody part of each bundle is increased on its *outer* side, and the bark part on its *inner* side. In the mean time the cambium between the bundles gives rise to new bundles, which then increase in size in the manner described above. The woody part of the stem soon comes to have the shape of a cylinder, surrounded by a softer bark portion as a sort of sheath.

470. The stem grows in thickness in the warm part of the year, but stops its growth as cold weather comes on. The first growth in each year is most vigorous, the cells being larger, while those formed towards the end of the season are regularly smaller and smaller until activity ceases. This manner of growth produces the well-known growth-rings, so readily seen in a cross-section of any pine or spruce stem. As there is generally but one period of growth each year in the cooler climates, every growth-ring represents a year of the tree's life; but it appears that occasionally there may be two periods of growth in a year, and consequently two growth-rings.

471. Many members of this class have canals running through the tissues of their stems and leaves, in which a resinous turpentine is found.

Practical Studies—(*a*) In the spring of the year collect a quantity of the staminate cones of a pine (Scotch or Austrian are very good), and preserve such as are not wanted for immediate use in alcohol. Collect at the same time the young ovule-bearing cones which are to be found upon the ends of the new shoots as ovoid bodies, 8 to 10 mm. long by 5 to 6 broad.

(*b*) Split a staminate and an ovule-bearing cone vertically, and study their structure, comparing the one with the other. Dissect out a stamen and an ovule-bearing scale, and compare. In the former note the pollen-sacs, and in the latter the ovules (Figs. 120 and 122).

(*c*) Study pollen-cells from young and mature staminate cones. In the young pollen look for the cells representing the first stage (prothallium); in the ripe pollen note the bladder-like enlargements of the outer coat (Fig. 121, *B*).

(*d*) Note that the ovule-bearing cones of Scotch and Austrian pines are two years in coming to maturity. Make vertical sections of cones of various ages, and note the growth of the seed. Note the thin wing (useful in their dispersion) on the seeds. Make longitudinal sections of seeds, and note the little plantlet with its several leaves (cotyledons).

(*e*) Make cross-sections of leaves, and note the turpentine-canals, one near each angle, with others symmetrically arranged between. Make cross-sections of the young twigs, and note the canals in the rind or bark. Make similar sections of the wood of the trunk, and note similar canals at intervals.

(*f*) Make very thin cross-sections of the mature wood of the stem, and note shape and size of the cells; note also the gradual decrease in the size in passing from the inner to the outer side of a growth-ring. Now make a very thin longitudinal-radial section, and observe the bordered pits (Fig. 126). A longitudinal section at right angles to the last (longitudinal-tangential) will show no bordered pits. In all these sections note that the wood is made up of but one kind of cells, viz., tracheïds.

(*g*) In a cross-section of a stem, note the thin radiating plates of tissue (medullary rays), in many cases extending from pith to bark. In longitudinal-tangential section of the stem these rays are seen in cross-section to be made of thick-walled cells (stony tissue). In longitudinal-radial sections the rays are seen split lengthwise (Fig. 126, *sl*).

(*h*) Make very thin cross-sections of the stem through bark and wood, and note the layers of very soft thin-walled tissue (cambium) between wood and bark. This may be made more evident by soaking the section for a few hours in carmine, by which the cambium will be stained.

There are three orders of Gymnosperms, viz.:

472. **The Cycads** (*Order Cycadaceæ*) are large or small trees, with much the general appearance of the palms and

tree-ferns. They are of slow growth and are long-lived; the stem elongates by a slowly unfolding terminal bud, which gives rise to a crown of widely spreading pinnate leaves, which are constantly renewed above as they die and fall away below. About seventy-five species are now known, all confined to tropical or sub-tropical climates. In geologic times (Triassic and Jurassic) they were very abundant.

473. **The Conifers** (*Order Coniferæ*) are mostly trees of a considerable size, with branching, spreading, or spiry tops, as the pines, spruces, firs, etc. etc. They are generally of rapid growth, and in many cases attain a great height and diameter. In the greater number of species the leaves are persistent, and the trees, consequently, evergreen.

474. The order contains thirty-two genera and about three hundred species, which are distributed mainly in the cooler climates of the globe. Seventy or more species occur within the limits of the United States, and constitute in many places enormous forests hundreds of miles in extent.

The pines (Pinus) include the most important trees of the order. The White pine (P. strobus), formerly very abundant from the Great Lakes eastward, furnishes the greater part of the "pine lumber" so largely used in the Northern States for building and other purposes. The Sugar pine (P lambertiana) of California resembles the White pine but is much larger, being often 60 to 90 metres (200 to 300 feet) in height, with a trunk 3 to 6 metres (10 to 20 feet) in diameter. The Southern pine (P. australis), abundant from the Carolinas to Texas, is a tree of moderate dimensions, whose hard wood is "superior to that of any other North American pine," and is known in the markets as Yellow or Georgia pine. Scotch pine (P. sylvestris) and Austrian pine (P. laricio), both natives of Europe, are extensively planted in this country. Besides the spruces, firs, larches, cedars, and many other well-known trees, the order contains the two species of great Redwoods. The most remarkable is called the Big Tree (Sequoia gigantea), and grows in a few valleys on the western slope of the Sierra Nevada Mountains in California. It attains a height of more than 100 metres (300 feet) and a diameter of 6 to 10 metres (20 to 30 feet). The other species is the common Redwood (S. sempervirens), confined to the coast-range mountains of California. It is but little inferior to the preceding in size, and its wood is extensively used for building and other purposes.

In the Southern Hemisphere the Kauri pine (Agathis australis) of New Zealand, the Norfolk Island pine (Araucaria excelsa) of the South Pacific Ocean, and others represent a group of conifers closely related to those which were abundant in ancient geological times.

475. **The Joint-Firs** (*Order Gnetaceæ*) include a few undershrubs or small trees, mostly natives of the warmer parts of the world. Their curious structure is far too difficult to be taken up here.

CLASS II. ANGIOSPERMÆ (*the Angiosperms*).

476. The plants of this class have, in most cases, more or less elongated stems; these are solid at first, and in the great majority of cases they remain so. They usually bear ample leaves, with parallel or netted veins.

477. Their reproductive organs are mostly collected into definite and distinct flowers, which often show great beauty of form and color. The pollen-bearing leaves (stamens) resemble those of the Gymnosperms, but the ovule-bearing leaves (carpophylls) are folded into a closed vessel (ovary).

478. Most Angiosperms are terrestrial and chlorophyll-bearing plants; there are, however, many aquatic and aerial species and a considerable number of parasites. They range, also, in size and duration, from minute annuals, a millimetre in extent, to enormous trees, 50 to 150 metres high and many centuries old.

479. We have seen (pp. 216–218) that in the Gymnosperms the flower consists of a stem upon which are the leaves

which bear reproductive cells. The flower of the Angiosperms is likewise a stem, bearing leaves which have to do with reproduction. In this class, however, there is, as a rule, a division of labor, as we may say: instead of all the leaves bearing reproductive cells, some of them are modified in form, color, or structure, so as to make the flower more conspicuous, which is, as we shall see, to the advantage of the plant.

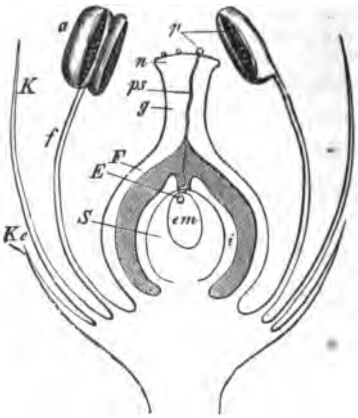

FIG. 127.—Diagrammatic section of a flower. *Ke*, calyx; *K*, corolla; *f*, the filament, and *a*, the anther, of the stamen; *p*, pollen-cells, some in the anther, others on the stigma; *F*, the ovary, surmounted by the style, *g*, and the stigma, *n* (this ovary contains one ovule, which has a single coat, *i*, enclosing the ovule-body, *S*); *em*, the embryo-sac; *E*, germ-cell; *ps*, a pollen-tube penetrating the style, and reaching the germ-cell through the micropyle of the ovule.

480. There are so many particular forms of flowers that it would be impossible to notice or describe them all in this place. In some cases the flower is a little stem (axis) upon which are pollen-bearing or ovule-bearing leaves (stamens or ovaries); these clusters of reproductive organs may have a number of sterile leaves below them on the stem, the floral leaves, or perianth. In other cases both kinds of re-

productive organs are in one flower, when the ovaries are highest on the stem, the stamens being next, and the sterile leaves (if any) lowest of all (Fig. 127). There is, moreover, great diversity in the development of the sterile leaves, varying from a few small green or pale leaves to two or more distinct whorls of sepals (the outer) and petals (the inner) which may show great differences in size, shape, texture, and color.

481. The stamens of Angiosperms often bear so little resemblance to leaves that their real nature would not be suspected. There is usually a slender stalk, the filament, at the top of which are from one to four pollen-sacs, the latter forming the anther. We may regard the filament and its extension (the so-called connective) between the pollen-sacs as representing a very narrow leaf upon which the pollen-sacs develop as outgrowths. Sometimes the stamen is broad, showing at once its leafy nature.

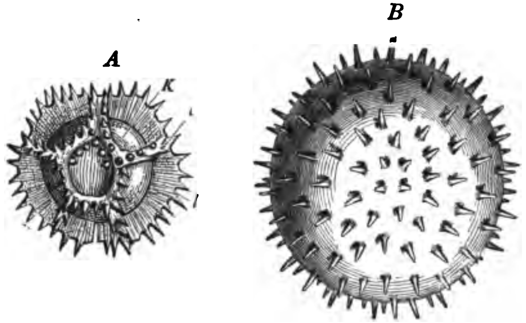

Fig. 128.—Pollen-cells with roughened walls. *A*, **of Chicory;** *B*, **of Flowering Mallow (Lavatera). Highly magnified.**

482. The development of the pollen-cells is like that of the spores of Fernworts and the pollen of Gymnosperms. Certain internal cells (called pollen mother-cells) in the

young pollen-sacs undergo division into four parts, which become rounded and covered with a double coat or wall. The outer coat is often much thickened, and may be roughened by ridges or prickles (Fig. 128).

483. The pollen-cells germinate in moisture, by sending out a tube which is a prolongation of the inner coat. In some cases there are cells or nuclei in the cell or tube, evidently representing the first stage (prothallium) in its last stages of suppression. The protoplasm of the cell passes freely down the tube to its extremity.

484. The ovule-bearing leaves of Angiosperms bear still less resemblance to ordinary leaves than do the stamens. In the simpler cases the young leaf becomes curved so that its edges touch and finally grow together, forming the ovary, which usually tapers above into a style or stalk supporting a glandular structure, the stigma (Fig. 127, *n*). The whole ovule-bearing organ, composed of ovary, style, and stigma, is usually known as the pistil. In many plants several pistils grow together, and thus form a compound pistil.

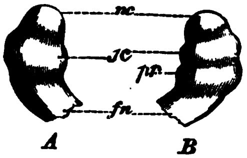

FIG. 129.—Very young ovules. *nc*, ovule-body; *sc*, inner, and *pr*, outer, coats just beginning to grow; *fn*, ovule-stalk. Magnified 140 times.

485. The ovules grow upon the inner (i.e., upper) surface of the leaf which forms the ovary, or at its base (Fig. 127), or more frequently upon its margins. At first it is a simple rounded outgrowth of a few cells; as it grows older a circular ridge arises upon it, which often is soon followed by another (Fig. 129, *A* and *B*). These ridges grow out and upwards so rapidly that they overtake and enclose the ovule-body, leaving but a small opening or pore.

486. The embryo-sac is an enlarged cell, at maturity containing several rounded masses of protoplasm, one of which is the germ-cell. As the tissues of the ovule-body can sufficiently nourish the germ-cell, there is little or no development of the first stage (prothallium) at this time, and there is an almost complete suppression of the archegone-walls.

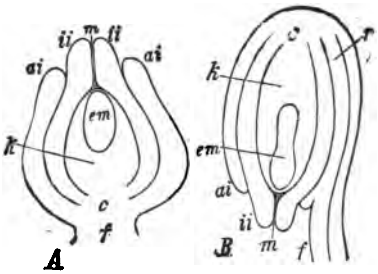

Fig. 130.—Diagrammatic longitudinal sections of ovules. *k*, the body of the ovule, with its embryo-sac, *em*; *ai*, the outer, and *ii*, the inner, coat; *m*, the opening in ovule-coat (micropyle); *c*, the base of the ovule; *f*, the ovule-stalk; *A*, a straight ovule; *B*, an inverted ovule: the long stalk, *f*, has fused with the outer coat of one side of the ovule.

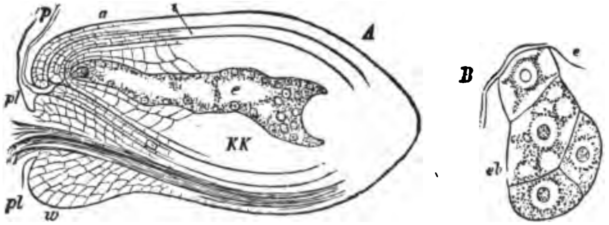

Fig. 131.—*A*, a longitudinal section of an ovule of the Pansy, after fertilization; *a* and *i*, coats of the ovule; *p*, pollen-tube; *e*, embryo-sac, with the very young embryo at one end and free endosperm-cells at the other. *B*, apex of embryo-sac, *e*; *eb*, very young embryo of four cells.

487. Fertilization takes place as follows: The pollen-cell, resting upon the moist surface of the stigma, germinates, and its tube penetrates the soft tissues of the stigma and style, finally reaching the cavity of the ovary, where

it enters the ovule through the opening in the coats (Fig. 131, *A*). Here it comes in contact with the apex of the ovule-body, and soon reaches the embryo-sac. The contents

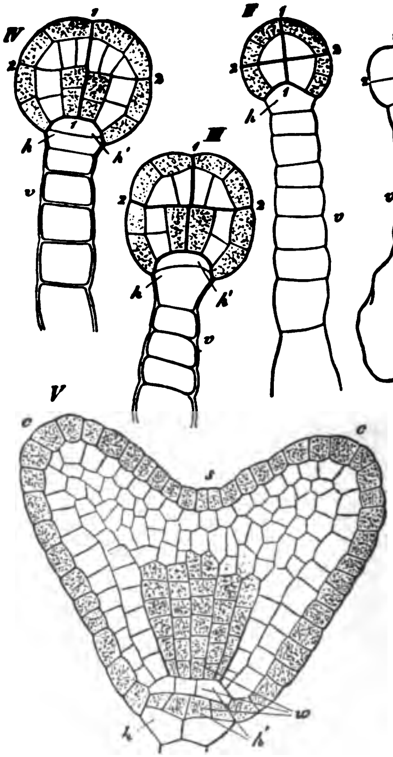

FIG. 132.—Embryo of Shepherd's Purse (Capsella), in various stages. *v*, the suspensor. In *V* the root-cells, *w*, first appear, the rudimentary leaves, *c*, *c*, and stem, *s*, already formed. Highly magnified.

of the pollen-tube unite with the germ-cell, which then forms a wall about itself; it then divides transversely one or more times, forming a row of cells (the suspensor), at the end of which an embryo soon begins to form by the fission of cells in three planes (Figs. 131, *B*, and 132, *I* to *IV*).

488. At first the embryo is a minute rounded cell-mass attached to the end of the row of cells, and in some plants it passes but little beyond this stage until after the ripening of the seed. In most cases, however, the cell-mass continues its growth until it has formed a little stem bearing rudimentary leaves above and a root below. There are to be found all degrees of simplicity in the embryos of Angiosperms, from the rounded cell-mass (thallus) to the well-formed plantlet provided with distinct root, stem, and leaves.

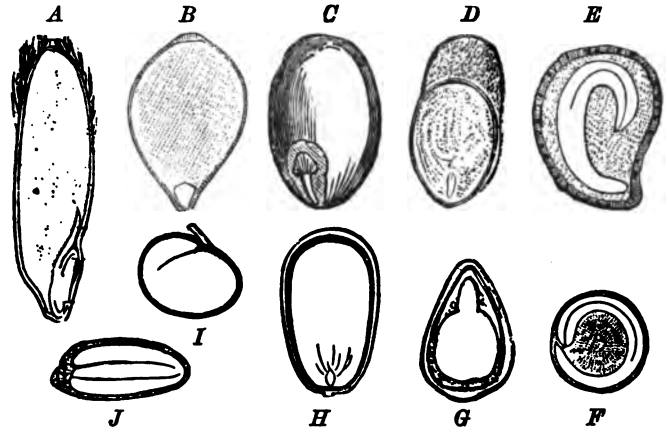

FIG. 133.—Magnified sections of seeds, showing embryos and endosperms. *A*, Oat; *B*, Sedge; *C*, Coffee; *D*, Marsh-marigold; *E*, Bitter-sweet; *F*, Goosefoot; *G*, Nettle; *H*, Oak; *I*, Sweet Pea; *J*, a Mustard. In *A* to *D*, small or minute embryo in large endosperm; *E* to *G*, larger embryo and smaller endosperm; *H* to *J*, large embryo and no endosperm.

489. While these changes are going on, cells arise in the basal part of the embryo-sac and increase rapidly, generally filling up a considerable part of its cavity. These cells

constitute the endosperm, and serve somewhat later to nourish the growing embryo. This nourishing tissue is considered to be the homologue of the first stage (prothallium) of the Fernworts, here greatly belated.

490. The embryo in its growth gradually absorbs the endosperm. In many cases growth is checked in the ripening of the seed, before much of the endosperm is used up (Fig. 133, *A* to *D*); in such seeds the embryo is small and poorly developed. In other cases more (Fig. 133, *E* to *G*), or in still others all (Fig. 133, *H* to *J*), of the endosperm is absorbed; in these the embryos are much larger and better developed. Where endosperm remains in a seed, its cells are generally filled with starch, or less frequently with oily matters; where no endosperm remains, there is always a storage of starch or oily matter in some part of the embryo. While the embryo is growing inside of the ovule, the outer ovule-coat generally becomes thicker and harder, all the ovule-tissues become drier, and at last the hard, dry ovule, now called a seed, separates at its base and falls to the ground.

491. The seed in germinating absorbs moisture, swells up, and generally bursts its coat. The embryo resumes its growth, sending out its root into the soil, and its stem and leaves upward into the air. Where there is endosperm, the embryo grows by absorbing food from it; where there is no endosperm, the large embryo is strong enough to grow for a time by using the store of food contained within itself. In some cases (e.g., bean, squash, melon, etc.) all the leaves withdraw from the seed-coat and appear above ground, while in others the first one or two leaves (cotyledons) remain in the seed in the ground, only the succeeding leaves coming up into the light and air, as in peas, wheat, etc.

492. We have seen that fertilization of the germ-cell not only caused the latter to develop into a plantlet, but excited the tissues of the ovule to a growth which they would not have made otherwise. This excitation of growth extends much further than the ovule; it commonly causes the ovary to undergo considerable changes, and in some cases even parts of the perianth or the stem which bears the organs of the flower. These changes give rise to the *fruit* of Angiosperms.

493. The changes which most frequently take place in the growth of the fruit are such as (1) an increase in the number of ovule-chambers by the formation of false partitions, or (2) a decrease in their number by the obliteration of some; (3) the growth of wings or prickles upon the exterior of the fruit; (4) the thickening and formation of a soft and juicy pulp; (5) the hardening of some portions of the wall by the development of stony tissue; (6) the thickening and growth of the calyx or receptacle.

494. In cases where the walls remain thin and eventually become dry, the fruits are said to be *dry*—e.g., in the bean; where the walls become thickened and more or less pulpy, they are *fleshy*—e.g., the peach.

495. It is unnecessary here to describe the various kinds of fruits. It is enough to point out that they all appear to have to do with the protection or dispersion of the seeds they contain. Thus the hard walls (as of nuts, achenes, etc.) or the bitter pulp of some (as of certain berries) are protective, while the sweet pulp (many berries, drupes, etc.) and explosive capsules of others serve to distribute the seeds.

496. The particular structure of the flower, its position on the plant, and its relation to other flowers in forming

flower-clusters of this or that shape, all have reference to pollination (i.e., the placing of the proper pollen upon the stigma). The pollen-cells are dependent for transportation to the stigma upon (1) the wind (*anemophilous* flowers); (2) certain contrivances by means of which insects (or rarely birds) are made to carry the pollen from anther to stigma (*entomophilous* flowers); (3) the favorable position of the anthers and stigmas, bringing the pollen in the opening anther into contact with the stigmatic surface (*autogamous* flowers).

497. The grasses and sedges, and the oaks, beeches, chestnuts, walnuts, birches, and their allies, and a few others, have wind-pollinated flowers. In these the pollen is produced in great abundance, and the flowers are mostly small, regular in form, simple in structure, uncolored, and destitute of nectar (honey). The pollen-bearing flowers are always in clusters which are exposed to the wind, as in grasses at the top of the plant.

498. A great number of plants have insect-pollinated flowers; these are, as a rule, large, colored, sweet-scented, and provided with nectar-glands; the nectar acts as a bait, and the showiness and scent as guides, to honey-loving insects, which, by various contrivances in the flowers, are made to come in contact with the anthers of one flower and the stigmas of another, in the first dusting their bodies with pollen, which in the second adheres to the stigmas.

499. Large flowers are frequently solitary, but smaller ones are, as a rule, massed in clusters which thus become conspicuous. In the golden-rods we have a good illustration of an extreme case of this kind, the individual flowers being very small and inconspicuous, while the flower-clusters of hundreds of massed flowers may be seen for a long

distance. In sunflowers, in addition, the marginal flowers in the cluster develop an especially showy perianth, surrounding the whole with conspicuous rays.

500. Many showy flowers have no nectar (honey) glands, but in general some part of the flower secretes a sweet, sugary fluid which is attractive to insects and some birds. The nectar is always situated in the back part of the flower, so that in securing it the insect is obliged to come near to the pollen-sacs or stigma.

501. In this connection the various irregularities of size and form in the parts of the perianth, as well as of stamens and pistils, have a meaning. Thus the perianth-leaves may grow together into a tube, in which case the nectar is at its bottom; or they may be of different sizes, as in orchids, beans, peas, etc., where they are so placed as to admit of access to the nectar from one direction only. In some tubular flowers there are two forms in the same species, those of some plants having long stamens and short styles, while in others the structure is exactly the reverse. Insects in getting honey from these will pollinate the long-styled flowers with pollen from the long stamens of other flowers, and *vice versa.* There is also very often a greater or less difference in the time of maturity of the stamens and pistils. In some the pollen is set free before the stigma is ready for pollination; in others it is the reverse. This (and the preceding) arrangement prevents pollination of a pistil by pollen from the stamens of the same flower; i.e., close fertilization is prevented.

502. Self-pollinated (autogamous) flowers are much less numerous than those which are wind- or insect-pollinated, and it is doubtful whether there are any species of plants all of whose flowers exhibit constant self-pollination (au-

togamy). There are a good many plants, however, which have two forms of flowers, viz., large, showy, nectar-bearing, insect-pollinated ones, and small, inconspicuous self-pollinated ones, generally with a rudimentary perianth. Flowers exhibiting this form of autogamy are said to be *cleistogamous.*

503. Examples are to be met with in some violets, wild touch-me-not, etc.: early in the season these have large flowers, which are pollinated by insects, but later only small cleistogamous ones appear, and in some violets these are subterranean. Without doubt it frequently happens that the pollen of wind- and insect-pollinated flowers falls upon their stigmas, resulting in accidental self-pollination; but too frequent a recurrence of this is guarded against by various structural devices.

504. The foregoing are but a few of the general modifications for securing proper pollination which flowers show; they must serve to direct the student's attention to this interesting part of the study of plants, which can be taken up in connection with the writings of Darwin, Müller, Gray, and others.

Practical Studies.—(*a*) Collect a few wild buttercup flowers. Begin at the lower side of the flower and carefully remove the five green sepals constituting the so-called calyx, next the five yellow petals constituting the so-called corolla, next the many stamens, and last the numerous small pistils which cover the rounded end of the floral stem. Make a careful drawing of a representative of each part.

(*b*) Mount in water (after moistening with alcohol) a little of the pollen of the morning-glory, sunflower, mallow, and Indian corn. Note the surface markings. Crush the cells and test with iodine. Pollen-grains may be germinated by placing them in a five-per-cent solution of common sugar in water. The pollen-tubes may also be found by carefully mounting stigmas or longitudinal sections of stigmas. Many grasses are good subjects for such studies.

(*c*) Remove the pistil from a fresh pea-flower. Split it longitudinally, and observe that the ovules are in a row along one seam (suture).

Make many cross-sections of another pistil, so as to secure sections of ovules, in which note the ovule-body and the coats. Make cross-sections of younger and younger unopened flowers of the pea, and study the development of the ovary and ovules. It is very easy to get specimens showing the ovary not yet closed, and the ovules as very small outgrowths from its margins.

(*d*) Make longitudinal sections of several young pea-pods in such manner as to secure thin sections of the ovules. By selecting pods of different ages, the large embryo sac, with the young embryo in various stages of growth, may be observed.

(*e*) Carefully dissect and examine a pea after soaking over night in water. Note the short curved stem, tipped by a root, the two thick starch-gorged leaves (cotyledons) with smaller leaves between them. Examine in like manner a bean, seeds of the apple, squash, buckwheat, oat, Indian corn. Note the endosperm when present.

(*f*) Examine in succession ripened fruits as follows: 1, marsh-marigold (follicle); 2, pea (legume); 3, mustard (capsule); 4, parsnip (cremocarp); 5, oak (nut); 6, sunflower (achene); 7, Indian corn (caryopsis); 8, melon or cucumber (pepo); 9, gooseberry (berry); 10, cherry (drupe); 11, apple (pome). Numbers 6 and 7, which are popularly called seeds, are composed of a large seed enclosed in a tightly fitting ovary-wall.

(*g*) Study the Indian corn as an example of a wind-pollinated (anemophilous) plant. Note the position of staminate (in the tassel) and pistillate (in the ear) flowers. Estimate the relative number of pollen-cells, and ovules (one in each ovary).

(*h*) Study the position of the nectar in clover (at the bottom of the corolla), columbine (in deep sacs of the petals), and buttercup (on glands at the base of the petals).

(*i*) Examine flowers from several different plants of eyebrights (Houstonia), puccoon (Lithospermum), and cultivated primrose. Observe that on some plants the flowers have long stamens and short styles, while in others they are the reverse. By measurements the anthers of the one form will be found to have exactly the height of the stigmas of the other. Many other flowers show this dimorphism; a few show trimorphism, i.e., three forms.

(*j*) Observe the flowering of spring-beauty (Claytonia), and notice that the stamens mature before the stigmas are ready for pollination. Observe in like manner thistles and sunflowers in which proterandry, as it is called, takes place also. Now observe the flowering of the strawberry and the apple, in which the pistils mature before the stamens. This is known as proterogyny. Both proterandry and proterogyny are included under the general term of dichogamy.

(*k*) Observe the large early flowers of violets, which are dependent upon insects for pollination. Notice that after a while none of these appear, but only small ones destitute of petals. In the common yellow violet these are borne on the stem above the ground, but in blue violets they are often underground. These small flowers are self-pollinated (cleistogamous).

505. The fibro-vascular bundles of the stems of Angiosperms are entirely of De Bary's "collateral" class; that is, each bundle in cross-section is more or less distinctly two-sided, viz., wood and bark. Each of these sides generally contains soft, fibrous, and vascular tissues.

506. The disposition of the bundles in the Angiosperms is for the most part dependent upon the position of the leaves. Nearly all the first-formed bundles are of the kind termed "common bundles;" that is, they extend on the one hand into the leaf, and on the other down into the stem.

507. The general arrangement may be illustrated by Fig. 134, in which there pass down from each leaf three bundles; at the lower internode these are, on the left, *a*, *b*, *c*, and, on the right, *d*, *e*, *f*. At the next internode, where the leaves stand at right angles to the lower ones, there are three bundles again, *g*, *h*, *i*, and *k*, *l*, *m*; these are largest at their points of curvature, and they dwindle in size as they pass downward and finally unite with the bundles from the lower pair of leaves. The bundles from the third internode pass downward, and in like manner join those from the second pair of leaves, and so on. Thus in such a stem every bundle passes downward through one internode before joining another, and in any internode all the bundles are derived from the leaves at its summit.

508. In some Angiosperms the bundles in a cross-section of a stem are separate from one another, while in others

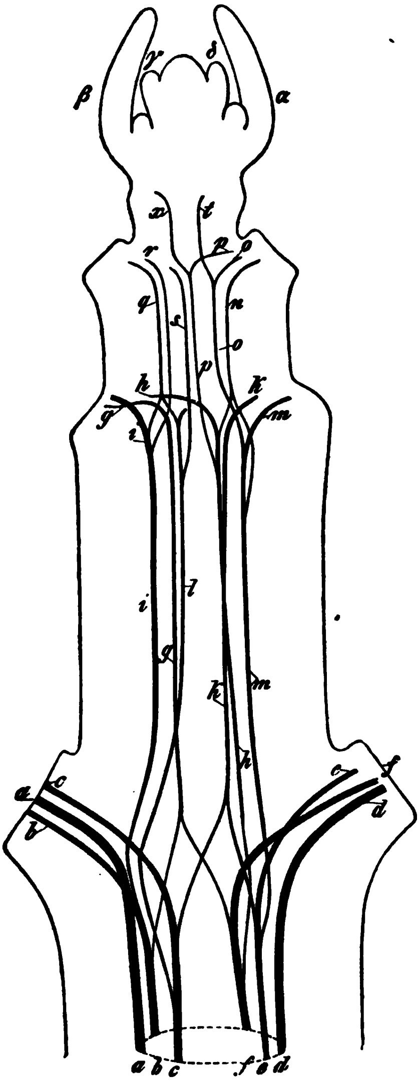

FIG. 134.—The fibro-vascular system of the stem of a Virgin's-bower (Clematis).

they soon become connected by a cambium-ring as in the Gymnosperms. In the perennial species this gives rise to a marked difference in the structure of the stem (Fig. 135, *A* and *B*).

509. The tissues of Angiosperms are the most varied and highly developed of any in the vegetable kingdom. Not only is every tissue abundantly represented, but each one shows almost numberless more or less well-marked varieties. Moreover, the structures which they form, as the solid (woody) parts of the stems, are of a higher order and far more complex than those in any other groups of plants.

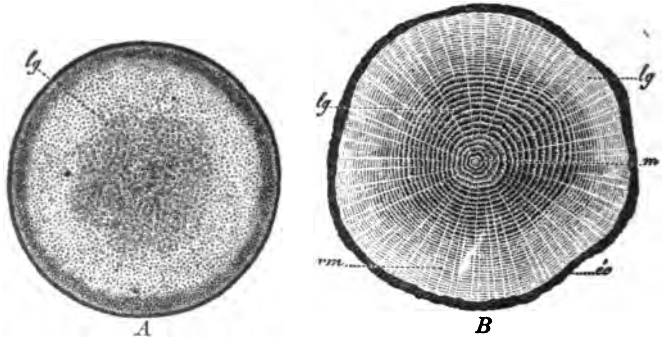

FIG. 135.—Cross-sections of tree-trunks. *A*, of a Palm; *B*, of an Oak; *lg*, woody, and *ec*, cortical (bark), portion; *m*, pith; *rm*, medullary rays.

Practical Studies.—(*a*) Make cross-sections of young stems of the asparagus and hickory. Note the difference in arrangement of the bundles. In like manner compare cross-sections of young stems of virgin's-bower (Clematis) and green-brier (Smilax).

(*b*) Make vertical sections of the foregoing, and note the relation of the bundles to the leaves.

(*c*) Make cross and longitudinal sections of the solid (woody) part of a bamboo or green-brier stem, and compare with similar sections of oak or hickory. In the latter note the pith, medullary rays, and distinct bark, not present in the former.

(*d*) In the sections of oak and hickory note the cambium-zone which lies between the inner solid (woody) mass and the outer softer portion.

510. The Angiosperms are readily separated into two sub-classes, as follows:

Sub-Class I. Monocotyledones (the Monocotyledons).—The first leaves produced by the embryo are alternate; the endosperm is usually large and the embryo small.

Sub-Class II. Dicotyledones (the Dicotyledons).—The first leaves of the embryo (cotyledons) are opposite; the endosperm is very often rudimentary or entirely wanting, and the embryo is generally large.

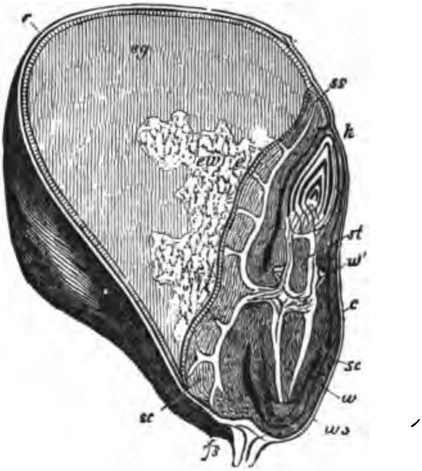

FIG. 136.—Longitudinal section of the seed of Indian Corn. *c*, adherent wall of the ovary; *n*, remains of the style; *sf*, base of the ovary (all the remainder of the figure is the true seed); *eg*, *ew*, endosperm; *sc*, *ss*, cotyledon; *e*, its epidermis; *k*, young leaves; *w*, the main root; *w'*, roots springing from the stem. Magnified 6 times.

SUB-CLASS I. THE MONOCOTYLEDONS (*Monocotyledones*).

511. The first leaves of the embryo are alternate; hence we say that they have one cotyledon. The venation of the

leaves is for the most part such that the veins run more or less parallel to one another, and when they join each other enclose four-sided spaces; rarely, however, their veins are irregularly distributed and form an irregular network.

512. The germination of Monocotyledons may be illustrated by the Indian corn. Here the embryo lies partly imbedded in one side of the large endosperm (Fig. 136). The first leaf of the young plant (the cotyledon, or scutellum), *sc*, has its broad dorsal surface in contact with the endosperm; anteriorly it is curved entirely around the remainder of the embryo.

513. Under proper conditions the main root pushes through the root-sheath (*ws*, Figs. 136, 137). The plumule, consisting of a minute stem and a few rudimentary leaves, next pushes out through the upper end of the curved cotyledon (*II*, Fig. 137). The cotyledon remains in contact with the endosperm and absorbs nourishment from it for the sustenance of the growing parts. Lateral roots soon appear upon the main root, and adventitious ones arise

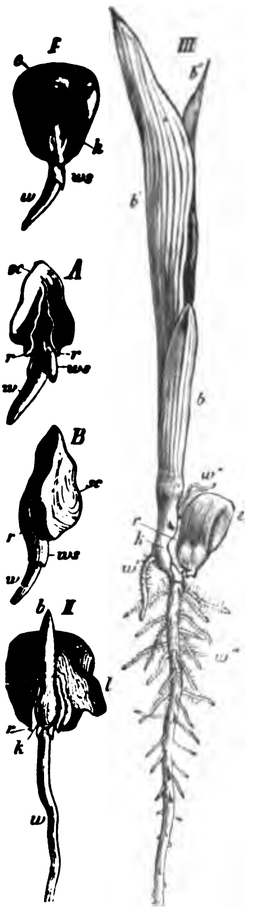

FIG. 137.—Germination of Indian Corn. *I*, *II*, *III*, successive stages. *A* and *B*, front and side views of a separated embryo; *w*, root; *e*, part of seed filled with endosperm; *sc*, cotyledon; *r*, its open margins; *b*, *b'*, *b''*, leaves of young plant; *l*, fragment of wall of ovary. Natural size.

from the first internodes of the stem (*w‴*, *w″*, *w′*). The first leaf above the cotyledon is quite small (*b*), and each succeeding one becomes larger and larger until the full size is reached.

514. Monocotyledons include about 18,000 known species which are by the latest authorities arranged under thirty-four orders. These orders, moreover, are brought together in seven groups (series). In the following tabular presentation only the more obvious characters are given.

Series I. Glumaceæ.—Perianth chaff-like or none. Ovary single, one-ovuled. Seeds with endosperm.

Order 1. The Grasses (Gramineæ).—Herbaceous or rarely woody plants with round, jointed, and mostly hollow stems, bearing alternate two-ranked leaves with split sheaths. Species 3100 to 3200, distributed in all climates.

Order 2. The Sedges (Cyperaceæ).—Herbaceous plants with three-angled solid stems bearing three-ranked leaves with entire sheaths. The 2200 species are distributed throughout the world.

Orders 3 to 5 (Restiaceæ, Centrolepideæ, Eriocaulonaceæ) include five or six hundred grass-like or rush-like, mostly tropical plants.

Series II. Apocarpeæ.—Perianth in one or two series or none. Ovaries single, or many always distinct. Seeds without endosperm.

Order 6, the Pondweeds (Naiadaceæ), Order 7, the Water-plantains (Alismaceæ), Order 8 (Triurideæ), mostly common water-plants, aggregating about 200 species.

Series III. Nudifloræ.—Perianth none. Ovaries single, or many united. Seeds mostly with endosperm.

Order 9. The Duckweeds (Lemnaceæ).—These are the smallest of flowering plants, and consist of floating discs generally bearing one or a few roots beneath. About twenty species are known, half of which occur in the United States.

Order 10. The Aroids (Aroideæ).—Herbs often large and palm-like in appearance, with large leaves having reticulated venation. There are about 900 species, distributed mostly in tropical countries, where they sometimes attain a height of several metres (6–12 feet); in temperate climates they are much smaller.

Order 11. The Cat-tails (Typhaceæ).—This small order is well represented by the well-known Cat-tail Flag of our ponds.

Order 12 (Cyclanthaceæ), of a few herbs, and Order 13, the Screw-pines (Pandanaceæ), of eighty shrubs or trees, are both tropical.

Series IV. Calycinæ.—Perianth small, calyx-like. Ovary free (i.e., not united to the perianth). Endosperm copious.

Order 14. The Palms (Palmaceæ).—Trees, shrubs, or woody climbers; natives almost exclusively of the torrid zone, or the adjacent hotter portions of the temperate zones, being rarely found beyond 40° north and 35° south latitude. Eleven hundred species of palms have been enumerated.

Order 15. The Rushes (Juncaceæ), of which there are 200 species, are widely distributed, while the very small Order 16 (Flagellarieæ) is confined to the tropics.

Series V. Coronarieæ.—Perianth more or less corolla-like. Ovary free, or rarely attached at the base. Endosperm copious.

Order 17 (Rapateaceæ) contains a few South American herbs.

Order 18, the Spider-worts (Commelinaceæ), includes about 300 mostly tropical herbaceous species.

Order 19 (Mayaceæ), Order 20, the Yellow-eyed Grasses (Xyridaceæ), Order 21 (Philydraceæ,) and Order 22, the Pickerel-weeds (Pontederiaceæ), are all small orders and consist of herbaceous species.

Order 23. The Lilies (Liliaceæ).—These are mostly perennial, herbaceous, rarely shrubby or tree-like plants, with entire leaves, and generally showy flowers. The species, of which there are about 2100, are distributed in all climates.

Order 24 (Roxburghiaceæ).

Series VI. Epigynæ.—Perianth more or less corolla-like. Ovary inferior (i.e., united to the perianth so that the latter appears to be on the ovary). Endosperm copious.

Order 25, the Yams (Dioscoreaceæ), and Order 26 (Taccaceæ), small orders of mostly tropical plants.

Order 27. The Amaryllids (Amaryllidaceæ) are mostly perennial herbs, widely distributed. About 650 species are known.

Order 28. The Irids (Iridaceæ) are perennial herbs numbering 700 species, very generally distributed throughout all regions.

Order 29. The Bloodworts (Hæmodoraceæ), a small order, natives mostly of the Southern Hemisphere.

Order 30. The Pine-apples and their allies (Bromeliaceæ), about 350 species of warm climates.

Order 31. The Bananas and their allies (Scitamineæ), perennial herbs, sometimes almost tree-like, numbering about 450 species, mostly tropical.

Series VII. Microspermæ.—Perianth more or less corolla-like. Ovary inferior. Seeds minute, without endosperm.

Order 32. The Orchids (Orchidaceæ) constitute an immense group of 4500 to 5000 species of perennial herbs. Some of these are terrestrial, while very many are epiphytic (i.e., grow upon trees: not parasitically, however).

Order 33 (Burmanniaceæ) and Order 34, the Frog's-bits (Hydrocharideæ), include about 100 species of small herbs.

515. The Monocotyledons include many of the most interesting plants botanically to be found in the vegetable kingdom. While the flowers in the lower orders are simple and unattractive, those in the higher series are often exceedingly complex and of great beauty. If, for example, we compare the flower of a grass with that of an Orchid, the differences are so great that at first we can scarcely see any resemblance. However, the two stand at opposite extremes, and, as may be seen by a study of the foregoing synopsis, there is a pretty regular gradation from the one to the other. From the Grasses through the Aroids to the Palms the gradation is an easy one, while from the Orchids through the Irids the passage is equally easy to the Lilies. We may, perhaps, regard the Palms and the Lilies as typical Monocotyledons between which lie a number of small connecting orders, and from which on either hand the orders diverge to specialized forms.

516. While the flowers of most grasses are wind-pollinated (anemophilous), those of the Orchids are almost entirely dependent upon insects for pollination. In the grasses we find a great amount of dry powdery pollen, but in the Orchids, on the contrary, the pollen is in small quantity and usually held together by sticky threads. The stigmas of grasses are large, prominent, and generally feathery, so as to easily catch and retain the pollen; in the Orchids, however, they are mostly sticky surfaces, rarely projecting, often much depressed.

517. These differences in the sexual organs are accompanied by similar ones in the surrounding parts. Thus the stamens and pistils in grass-flowers are surrounded by chaffy scales pale or green in color. Such flowers are therefore not conspicuous, although generally clustered at the summit of the stem. Moreover, they possess little or no nectar, and, with few exceptions, are scentless. In the Orchids there is a well-developed perianth which shows high specialization of form and color. Most are provided also with nectar-glands and an attractive odor.

518. In Orchid-flowers the stamens and styles are fused together into a "column" which occupies the centre of the perianth. In the great majority of cases there is but one anther (representing one stamen), and this is on or near the end of the column, so placed as to be readily touched by an insect entering the flower. The pollen-cells cohere in little sticky masses, which easily adhere to the head, antennæ, or back of an insect.

519. It is an interesting fact that in the ordinary terrestrial Orchids the flower develops in such a way that it must twist upon its ovary in order to attain its proper position when open (Fig. 138). Thus, without twisting, the lip (*l*) with its spur would be uppermost, while the anther would be below.

520. When a long-tongued insect is attracted to an Orchid-flower by the color and odor, it thrusts its tongue down into the spur (*sp*) in search of nectar or sweet juices, in the mean time perhaps resting its feet upon the lip (*l*). Its head comes in contact with the sticky discs (at *h*), which adhere tenaciously. When the insect withdraws its tongue, it at the same time carries away the pollen-masses adhering to its head. When the insect visits another Orchid-flower

of the same species, the pollen-masses are thrust against the sticky stigma (*st*) and all or a part adheres to it. Thus, as the insect passes from flower to flower, it unconsciously pollinates them, always, however, carrying the pollen of one flower to the stigma of some other.

521. The Lady's Slippers are examples of Orchids with two anthers; these are upon the sides of the curved column which bears the stigma higher up. The lip is here shaped like a slipper (whence the common name), into the opening of which the column bends. The lip and the other parts of the perianth are colored, often showing striking contrasts, and these doubtless serve to attract the notice of insects. When an insect enters the slipper (lip), it does so

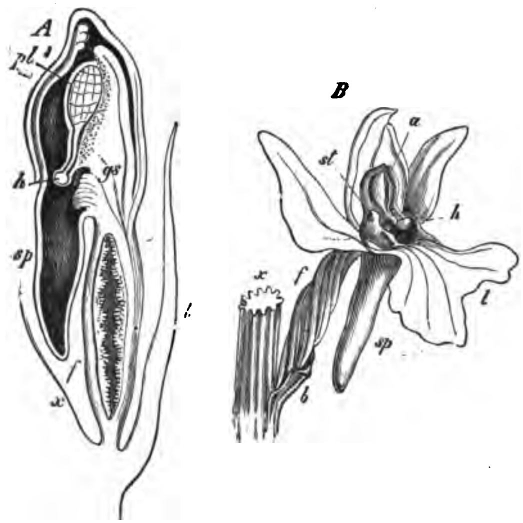

FIG. 138.—An Orchid-flower (Orchis mascula). *A*, vertical section of a flower-bud (magnified) before it has twisted upon its ovary, *f*; *gs*, the column, bearing a pollen-mass, *pl*; *h*, its sticky disc, below which is the stigma. *B*, an open flower; *f*, its twisted ovary; *l*, lip; *st*, stigma; *a*, anther; *h*, its sticky disc; *sp*, spur.

from the top; but once inside, it finds it difficult to escape by that route on account of the incurved margins of the opening, as well as the smooth sides of the slipper. It accordingly passes backward under the dependent stigma, and escapes by squeezing between the column and base of the slipper: in doing this it covers its back with sticky pollen from the anther on the column. When it visits another flower this experience is repeated; and as it passes under the stigma in its endeavor to find an exit, some of the pollen is left on its surface.

522. Among the tropical Orchids there are some marvellous flowers. One of the most remarkable of these is a large flowered species of Catasetum, native of South America. The flowers are diclinous, i.e., the pollen and the ovules are produced in different flowers. The column of the staminate flower is furnished with a pair of slender horns, one or both of which are sensitive. The pollen-masses are curved and in a state of tension, like a curved whalebone spring. Now, when an insect alights on the lip of the flower and comes in contact with one of the sensitive horns, the pollen-mass is instantly set free with a jerk sufficient to throw it nearly a metre, and in such a direction as to strike and adhere to the head of the insect. When the insect visits a pistillate flower, the pollen-mass is in the proper position to be brought in contact with the stigma, thus effecting pollination.

523. Much might be written about these truly wonderful plants, but what has been said must suffice to call the attention of the student to them. Our native species will well repay a careful examination, while the exotic ones, of which hundreds are now grown in conservatories, show a greater variety in form and color of flower than can be

found in any other order of plants. The student may profitably read in this connection Mr. Darwin's work, "The Various Contrivances by which Orchids are Fertilized by Insects."

524. The Monocotyledons include many of our finest ornamental plants. Thus some of the grasses and sedges are grown for the beauty of their foliage and flower-clusters, and many aroids find places in greenhouses, one of the most common being the so-called Calla-lily from South Africa. In the Lilies, however, we find the greatest number of plants grown for the beauty and attractiveness of their flowers, possibly excepting the Orchids. Of the Lilies proper there are many species from America, Europe, Asia Minor, China, and Japan which have long been in cultivation in gardens. Closely allied to these are the Day-lilies and the stately Crown-imperial, the Hyacinth, now of many forms and colors, and the Tulips, which under cultivation have been made to vary still more. The Amaryllids have given us the Snowdrop and Snowflake, the Daffodils, Jonquils, and the delightfully sweet-scented Tuberose. From the Irids we have many species of Iris and Crocus and Gladiolus, the last from South Africa. The use of the Orchids as ornamental plants has already been referred to; but while, doubtless, more species of them are grown, they are for the most part confined to special greenhouses and conservatories called orchid-houses, and are not found in common cultivation among the people at large.

525. The rank of the Monocotyledons economically is high. The seeds of the grasses have a copious starchy endosperm which has for ages been used as food for man and his domestic animals. Thus wheat, rye, barley, oats, and

rice, all natives of the old world, have been in cultivation from time immemorial. Indian Corn, being a native of America, has but recently come under general cultivation. The stems of most grasses are nutritious, and constitute the greater part of the pasturage and fodder for domestic animals. In several of the larger species, as the Sugar-canes, this nutritious matter is so abundant as a sweet juice that they furnish the greater part of the sugar of the world.

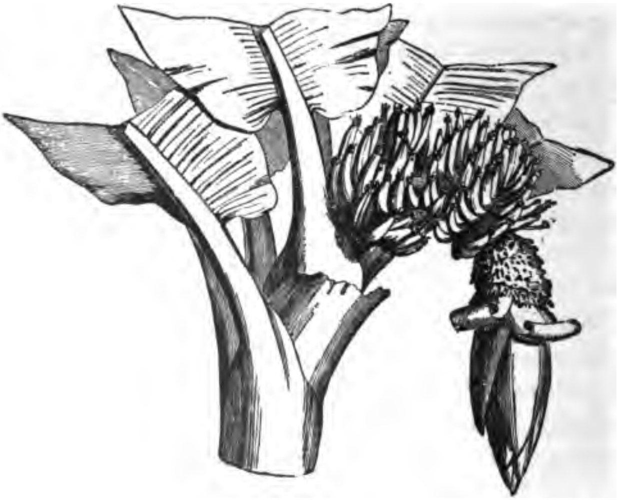

FIG. 139.—Part of a flowering plant of the Banana, showing the unfolding flower-bud and the young fruits.

526. The Palms, while of little value to the people of cooler climates, furnish in tropical regions most of the necessaries of life. In some countries every want of man is supplied by one or another of the palms. The Cocoa-nut-palm, now grown in all hot climates, is one of the most useful of the species, furnishing material for huts, fences,

baskets, buckets, ropes, mats, cups, food, wine, and many other purposes. The Date-palm of the Mediterranean region, the Palmyra Palm of Southern Asia, and the Sago-palms of Siam and the Indian Archipelago are all food-producing trees of great importance to the people of these countries.

527. The Bananas likewise furnish great quantities of food to the natives of tropical countries. There are several species and many varieties; all are large herbs with a palm-like aspect, often 3 to 5 metres (10–15 feet) high. Their fruits are borne at the summit of the stem, a large flowering bud gradually unfolding and exposing clusters of small flowers which produce the well-known fruits (Fig. 139)

SUB-CLASS II. THE DICOTYLEDONS (*Dicotyledones*).

528. The first leaves of the embryo are two and opposite; hence they are said to have two cotyledons. The venation of the leaves is for the most part such that the veins are rarely parallel, and in joining one another they form an irregular network.

529. The germination of Dicotyledons may be illustrated by the following examples. In the seed of the Windsor Bean (Fig. 140) the embryo entirely fills up the seed-cavity, the endosperm having all been absorbed. The thick cotyledons lie face to face, and are attached below to the small stem of the embryo-plant. The stem extends upward a short distance between the cotyledons, bearing a few rudimentary leaves and itself ending in a growing point, the whole constituting the *plumule*. The downward prolongation of the stem (commonly but erroneously called

the *radicle*, for it is *not* a little root) ends in a very short root which is continuous with the stem.

530. Under the proper conditions of heat and moisture, the root elongates and pushes out through the pore (micropyle) of the seed-coat; at the same time the stalks of the cotyledons elongate and thus bring the plumule outside of the seed-coat, the cotyledons alone remaining within. During the first few days of its growth the young plant is

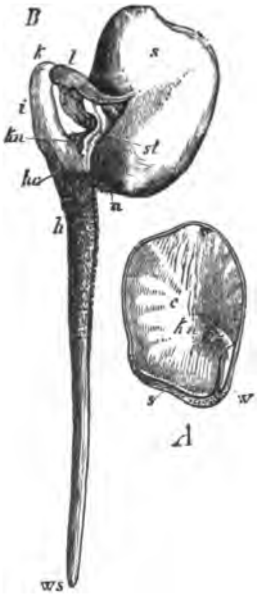

FIG. 140.

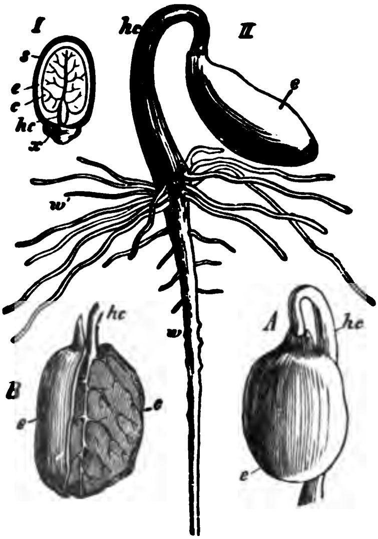

FIG. 141.

FIG. 140.—Windsor Bean (Vicia faba). *A*, seed with one cotyledon removed; *c*, cotyledon; *kn*, plumule; *w*, root; *s*, seed-coat *B*, germinating seed; *s*, seed-coat, partly torn away at *l*; *st*, stalk of one of the cotyledons; *k*, curved stem above, and *hc*, short stem below, the cotyledons; *h*, *ws*, root.

FIG. 141.—Castor-oil Plant (Ricinus communis). *I*, longitudinal section of the ripe seed. *II*, germinating seed with the cotyledons still inside of the seed-coat (shown more distinctly in *A* and *B*). *s*, seed-coat; *e*, endosperm; *c*, cotyledon; *hc*, stem; *w*, root.

nourished by the starch in the cotyledons, which in this species remain during the whole process of germination beneath the ground enclosed in the seed-coat. In the common Field-bean (Phaseolus) the germination is the same excepting that the stem elongates below the cotyledons and brings the latter above the ground.

531. The seed of the Castor-oil Plant contains a large embryo surrounded by a thin layer of endosperm (Fig. 141, *I*). In its germination the root and stem below the cotyledons elongate, and thus bring the seed-coat with the contained cotyledons above the ground (Fig. 141, *II*). The cotyledons remain within the seed-coat until they have absorbed all of the endosperm; when this is accomplished the empty seed-coat falls away, and the freed cotyledons expand and assume to some extent the function of ordinary foliage-leaves.

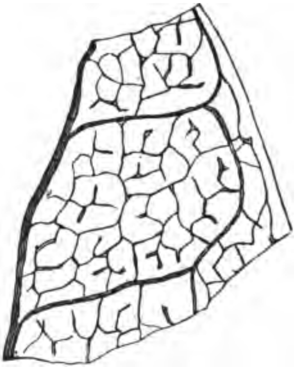

FIG. 142.—Magnified fragment of a leaf of a Dicotyledon, showing reticulated venation.

532. The venation of the leaves of Dicotyledons is easily studied by macerating them so as to remove the soft tissue, leaving only the fibro-vascular bundles. While there is as a rule a general likeness between them, there is yet an almost infinite diversity in the details of structure. The general disposition of the smaller veins is well illustrated by Fig. 142.

533. There are now known upwards of 78,000 Dicotyledons, showing every degree of development from minute

herbaceous annuals to large woody perennials. It is a most difficult matter to arrange so great a number of species satisfactorily, so as to show their mutual relationship. They have been grouped into about one hundred and sixty orders. The orders, again, have been grouped as far as possible in such a way as to bring together those which bear the closest resemblance to one another. The disposition of these groups is as yet partly artificial, in many cases resulting in the separation of orders which are evidently related.

534. The following synopsis will show the latest arrangement, as generally adopted in this country. For convenience three artificial groups are made, viz., Apetalæ, Gamopetalæ, and Choripetalæ.

I. APETALÆ. APETALOUS DICOTYLEDONS.

Plants whose flowers generally have but a single floral envelope (calyx) this even, in some cases, wanting.

Many of the orders here brought together are related to those to be noticed further on. Their flowers are in many cases to be regarded as simplified Choripetalæ, or less commonly Gamopetalæ. The grouping given below is almost entirely artificial.

Series I. ———. —Flowers mostly unisexual. Perianth none or small. A group of anomalous orders of doubtful relationship.

Order 1. The Hornworts (Ceratophyllaceæ) are a few small aquatics, widely distributed. The seeds contain a well-developed embryo and no endosperm.

Order 2. The Crowberries (Empetraceæ).—These are four small Heath-like shrubs producing berry-like fruits whose seeds contain a small embryo in copious albumen.

Order 3 (Lacitemaceæ), shrubby plants (16 species) of tropical America, producing dry fruits whose seeds contain a copious endosperm.

Order 4. The Willows (Salicaceæ) are trees and shrubs common in the Northern Hemisphere. They include also the Poplars, there being 150 or more species of true willows and 18 poplars now known. The flowers are unisexual, and the staminate and pistillate forms always occur on different plants (i.e., they are diœcious); they are destitute of a perianth and are clustered into weak spikes or catkins. The seeds contain a well-developed embryo and no endosperm.

Series II. Unisexuales.—Flowers unisexual. Perianth none or small. Seeds few or one, with little or no endosperm (excepting in Orders 12 and 13).

Order 5, the Oaks (Cupuliferæ), trees and shrubs mostly of the Northern Hemisphere, including, in addition to the oaks proper, the Beeches, Chestnuts, Ironwoods, Hazels, Birches, and Alders. Four hundred species are known.

Order 6, the Beefwoods (Casuarineæ), a few leafless trees and shrubs with green jointed branches having much the aspect of the horsetails (Equisetum).

Order 7, the Galeworts (Myricaceæ), a few aromatic shrubs producing drupe-like fruits.

Order 8, the Walnuts (Juglandaceæ), generally large trees bearing drupe-like fruits enclosing a stony shell. About 30 species are known, widely distributed throughout the Northern Hemisphere.

Order 9 (Leitnerieæ), and Order 10, the Plane-trees (Platanaceæ), each of a few species.

Order 11, the Nettleworts (Urticaceæ), a large group of herbs, shrubs, and trees (1500 species), often separated into several distinct orders. It includes the Elms, Hackberries, Figs, Mulberries, and in the tropics many other trees. The hop and hemp and many species of nettles are common representatives of the herbs of this order.

Order 12 (Balanopseæ), a few Australian woody plants.

Order 13. The Spurgeworts (Euphorbiaceæ) include 3000 or more species of herbs, shrubs, and trees, mostly rich in latex (contained in milk-tissue). The order is mostly tropical, where it abounds in large trees; but the few species found in colder climates are almost entirely small and herbaceous.

Series III. Achlamydosporeæ.—Perianth generally calyx- or corolla-like. Ovules few. Ovule-body without coats, the seeds therefore naked. Endosperm mostly present.

Order 14 (Balanophoreæ), Order 15, the Sandalworts (Santalaceæ), and Order 16, the Loranths, or Mistletoe Family (Loranthaceæ), are all more or less parasitic herbs or shrubs.

Series IV. Daphnales.—Perianth generally calyx-like. Ovules few. Endosperm wanting (with few exceptions). Mostly trees and shrubs with perfect flowers (i.e., with both stamens and pistils in the same flower).

Order 17, the Oleasters (Elæagnaceæ), a few scurfy-leaved shrubs and trees, widely distributed.

Order 18 (Penæaceæ), a few South African evergreen shrubs.

Order 19. The Daphnads (Thymelæaceæ) include about 360 tough-barked trees and shrubs (with a few herbs), mostly of the Southern Hemisphere.

Order 20. The Proteads (Proteaceæ) are strange-looking evergreen shrubs and trees (about 950 species), mostly natives of Australia and South Africa.

Order 21. The Laurels (Lauraceæ) are aromatic trees and shrubs of tropical and temperate climates. About 900 species are known.

Series V. Micrembryeæ.—Perianth mostly wanting. Ovules few. Embryo minute, in copious endosperm.

Order 22 (Monimiaceæ), Order 23, the Nutmegs (Myristicaceæ), and Order 24 (Chloranthaceæ) are aromatic trees and shrubs of hot climates, about 250 species in all.

Order 24*a*. The Peppers (Piperaceæ) are herbs, shrubs, or small trees, almost confined to the tropics; generally with a pungent and aromatic principle. About 1000 species are known.

Series VI. Multiovulatæ terrestres.—Perianth calyx-like. Ovary mostly inferior. Ovules numerous. Endosperm present. Terrestrial or parasitic plants.

Order 25, the Birthworts (Aristolochiaceæ), Order 26, the Vine-rapes (Cytinaceæ), curious parasites, and Order 27, the Pitcher-leaves (Nepenthaceæ), with curiously formed pitcher-shaped leaves.

Series VII. Multiovulatæ aquaticæ.—Perianth small or none. Ovary superior (i e., not united with the perianth). Ovules numerous. Endosperm wanting. Aquatic herbs.

Order 28, the Podostemads (Podostemaceæ), a small order, mostly tropical.

Series VIII. Curvembryeæ.—Perianth green or colored. Ovary superior. Ovules few. Seeds with endosperm, containing a curved embryo.

Order 29, the Buckwheats (Polygonaceæ), including 600 species, Order 30 (Batideæ), and Order 30*a* (Phytolaccaceæ) are mostly herbaceous, and mainly tropical.

Order 31, the Chenopods (Chenopodiaceæ), 520 species of all climates; Order 32, the Amaranths (Amarantaceæ), nearly 500 species of wide distribution; Order 33 (Illecebraceæ) and Order 34 (Nyctaginaceæ), 200 or more species, mostly tropical. All the orders of this series (excepting No. 30) contain many weedy plants.

II. GAMOPETALÆ. GAMOPETALOUS DICOTYLEDONS.

Plants whose flowers generally have both sepals and petals, the latter more or less united.

Here are grouped the orders containing plants showing the highest development in the vegetable kingdom. They are naturally arranged under ten cohorts, and these fall into three series.

Series IX. Bicarpellatæ.—Ovary mostly superior. Pistil generally composed of two carpophylls (leaves).

Lamiale Cohort (with irregular flowers).

Order 35, the Mints (Labiatæ); 2500, herbs or shrubs; temperate and warm climates.

Order 36, the Vervains (Verbenaceæ); 700, herbs, shrubs, or trees, mostly tropical.

Order 37 (Selagineæ); 140, shrubs or herbs, mostly South African.

Order 38 (Myoporineæ); 80, shrubs or small trees, mostly Australian.

Personale Cohort (with irregular flowers).

Order 39, the Acanths (Acanthaceæ); 1500, herbs, mostly tropical.

Order 40 (Pedaliaceæ); 40, herbs, mostly tropical.

Order 41, the Bignoniads (Bignoniaceæ); 500, mostly woody, and generally tropical.

Order 42 (Gesneraceæ); 700, herbs, shrubs, and rarely trees, of the tropics.

Order 43 (Columelliaceæ); 2, small evergreen trees, of tropical America.

Order 44, the Bladderworts (Lentibulariaceæ); 180, mostly marsh herbs of temperate and tropical climates.

Order 45, the Broom-rapes (Orobanchaceæ); 150, parasitic herbs, widely distributed.

Order 46, the Figworts (Scrophulariaceæ); 2000, herbs, shrubs, rarely trees, of all parts of the world.

Polemoniale Cohort.

Order 47, the Nightshades (Solanaceæ); 1250, herbs or woody plants, chiefly tropical.

Order 48, the Bindweeds (Convolvulaceæ); 800, mostly herbaceous climbers, chiefly tropical.

Order 49, the Borageworts (Boraginaceæ); 1200, herbs, shrubs, and trees, widely distributed.

Order 50, the Hydrophylls (Hydrophyllaceæ); 150, mostly American herbs.

Order 51, the Phloxes (Polemoniaceæ); 150, mostly American herbs.

Gentianale Cohort.

Order 52, the Gentians (Gentianaceæ); 520, herbs, common in mountain regions.

Order 53 (Loganiaceæ); 350, mostly shrubs and trees of the tropics.

Order 54, the Milkweeds (Asclepiadaceæ); 1800, mostly herbaceous, chiefly tropical.

Order 55, the Dogbanes (Apocynaceæ); 900, mostly trees and shrubs, rarely herbaceous, chiefly tropical.

Order 56 (Salvadoraceæ); 8, woody plants of hot climates.

Order 57, the Olives (Oleaceæ); 280, shrubs and trees, rarely herbs, of temperate and tropical climates.

Series X. Heteromeræ.—Ovary mostly superior. Pistil composed of more than two carpophylls (leaves).

Ebenale Cohort.

Order 58, the Storaxworts (Styracaceæ); 220, shrubs and trees of hot climates.

Order 59, the Ebonyworts (Ebenaceæ); 250, shrubs and trees of hot climates.

Order 60, the Star-apples (Sapotaceæ); 300, shrubs and trees of hot climates.

Primulale Cohort.

Order 61 (Myrsinaceæ); 500, shrubs and trees of hot climates.

Order 62, the Primroses (Primulaceæ); 250, herbs, mostly of the north temperate zone.

Order 63, the Plantains (Plantaginaceæ); 200, herbs, widely distributed. An anomalous order, probably to be placed here.

Order 64, the Leadworts (Plumbaginaceæ); 200, mostly herbs of temperate climates.

Ericale Cohort.

Order 65 (Lennoaceæ); 4 or 5, herbaceous root-parasites of California and Mexico.

Order 66 (Diapensiaceæ); 6 to 8, low plants, of cold regions.

Order 67, the Heaths (Ericaceæ); 1700, mostly shrubs and small trees, a few herbs, of wide distribution.

Series XI. Inferæ.—Ovary inferior.

Campanale Cohort.

Order 68, the Bellworts (Campanulaceæ); 1000, herbs, rarely shrubs, widely distributed.

Order 69 (Goodeniaceæ); 200, mostly herbaceous plants of the Southern Hemisphere.

Order 70 (Stylidiaceæ); 100, mostly herbaceous plants of the Southern Hemisphere.

Asterale Cohort.

Order 71, the Composites (Compositæ); 10,000 or more, mostly herbs, some shrubs, a few trees, of all parts of the world.

Order 72 (Calyceraceæ); 20, herbs of South America.

Order 73, the Teaselworts (Dipsaceæ); 120, mostly herbs, chiefly of the north temperate zone.

Order 74 (Valerianaceæ); 300, mostly herbs, chiefly of the north temperate zone.

Rubiale Cohort.

Order 75, the Madderworts (Rubiaceæ); 4100, trees, shrubs, and herbs, mostly tropical.

Order 76, the Honeysuckles (Caprifoliaceæ); 200, mostly woody plants of the Northern Hemisphere.

III. CHORIPETALÆ (POLYPETALÆ). CHORIPETALOUS DICOTYLEDONS.

Plants whose flowers generally have both calyx and corolla, the latter of separate petals.

Although this group is here placed last, it is composed of plants which must rank as structurally lower than those of the Gamopetalæ.

Series XII. Calyciforæ.—Calyx generally of united sepals. Stamens on the calyx-cup. Ovary frequently inferior.

Umbellale Cohort.

Order 77, the Cornels (Cornaceæ); 75, shrubs and trees, rarely herbs, mostly of the north temperate zone.

Order 78, the Ivyworts (Araliaceæ); 340, trees and shrubs, rarely herbs, mostly tropical.

Order 79, the Umbellifers (Umbelliferæ); 1300, herbs, rarely shrubs or trees, mostly of the north temperate zone.

Ficoidale Cohort.

Order 80, the Ficoids (Ficoideæ); 450, mostly fleshy herbs, chiefly of the tropics.

Order 81, the Cactuses (Cactaceæ); 1000, succulent herbs, shrubs, and trees, generally leafless, all American.

Passiflorale Cohort.

Order 82 (Datiscaceæ); 4, herbs and trees, of the Northern Hemisphere.

Order 83, the Begonias (Begoniaceæ); 350, herbs, mostly of tropical America.

Order 84, the Cucurbits (Cucurbitaceæ); 470, herbs or undershrubs, mostly tropical.

Order 85, the Passion flowers (Passifloraceæ); 250, trees, shrubs, and herbs, mostly of the tropics.

Order 86 (Turneraceæ); 76, herbs and shrubs, mostly tropical.

Order 87 (Loasaceæ); 100, mostly herbaceous tropical plants.

Order 88 (Samydaceæ); 150, trees and shrubs of the tropics.

Myrtale Cohort.

Order 89, the Onagrads (Onagraceæ); 300, herbs, shrubs, and trees of temperate climates.

Order 90, the Lythrads (Lythraceæ); 250, herbs, shrubs, and trees, mostly tropical.

Order 91, the Melastomads (Melastomaceæ); 1800, trees, shrubs, and a few herbs, almost entirely tropical.

Order 92, the Myrtles (Myrtaceæ); 1800, trees, shrubs, and a few herbs, mostly tropical.

Order 93 (Combretaceæ); 240, trees and shrubs, mostly tropical.

Order 94, the Mangroves (Rhizophoraceæ); 50, trees and shrubs, mostly tropical.

Rosale Cohort.

Order 95, the Hippurids (Halorageæ); 80, mostly aquatic herbs of wide distribution.

Order 96 (Bruniaceæ); 40, Heath-like plants of South Africa.

Order 97, the Witch-hazels (Hamamelaceæ); 30, shrubs and trees, mostly of warm climates.

Order 98, the Sundews (Droseraceæ); 110, mostly bog-herbs, widely distributed.

Order 99, the Crassulas (Crassulaceæ); 400, usually succulent herbs or shrubs, of temperate and warm climates.

Order 100, the Saxifrages (Saxifragaceæ); 450, trees, shrubs, and herbs, of temperate and cool climates.

Order 101, the Roseworts (Rosaceæ); 1000, herbs, shrubs, and trees, distributed throughout the world.

Order 102, the Leguminous Plants (Leguminosæ); 6500, herbs, shrubs, and trees, distributed throughout the world.

Order 103 (Connaraceæ); 140, trees and shrubs of the tropics.

Series XIII. Discifloræ.—Calyx of distinct or united sepals. Flowers usually with a conspicuous disc (i.e., broadened and thickened receptacle). Stamens on or at the base of the disc. Ovary superior.

Sapindale Cohort.

Order 104 (Moringeæ), and Order 105 (Coriarieæ); each with 3-4 species of woody plants, mostly of the old world.

Order 105, the Anacards (Anacardiaceæ); 450, trees and shrubs, mostly tropical.

Order 106 (Sabiaceæ); 32, trees and shrubs, mostly tropical.

Order 107, the Soapworts (Sapindaceæ); 600 to 700, trees and shrubs, rarely herbs, widely distributed.

Celastrale Cohort.

Order 108, the Vines (Ampelideæ); 250, mostly climbing shrubs of temperate and hot climates.

Order 109, the Rhamnads (Rhamnaceæ); 430, trees, shrubs, rarely herbs, of temperate and hot climates.

Order 110 (Stackhousieæ); 20, small herbs, mostly Australian.

Order 111, the Spindle-trees (Celastraceæ); 400, small trees and shrubs of temperate and hot climates.

Olacale Cohort.

Order 112 (Cyrillaceæ); 8, trees and shrubs of the hotter parts of America.

Order 113, the Hollies (Ilicineæ); 150, trees and shrubs of temperate and hot climates.

Order 114, the Olacads (Olacineæ); 170, trees and shrubs, mostly of the tropics.

Geraniale Cohort.

Order 115 (Chailletiaceæ); 38, trees and shrubs of the tropics.

Order 116, the Meliads (Meliaceæ); 270, trees and shrubs of the tropics.

Order 117 (Burseraceæ); 145, trees and shrubs of the tropics.

Order 118 (Ochnaceæ); 140, trees and shrubs, mostly of the tropics.

Order 119, the Quassiads (Simarubaceæ); 112, trees and shrubs of the tropics.

Order 120, the Rueworts (Rutaceæ); 650, trees, shrubs, rarely herbs, of tropical and temperate climates.

Order 121, the Cranesbills (Geraniaceæ); 750, mostly herbaceous plants of temperate and warm climates.

Order 122 (Zygophyllaceæ); 100, shrubs and herbs, rarely trees, of the tropics.

Order 123 (Malpighiaceæ); 580, trees and shrubs, mostly of the tropics.

Order 124 (Humiriaceæ); 20, balsamic trees and shrubs of the tropics.

Order 125, the Flaxworts (Linaceæ); 135, herbs, shrubs, and a few trees, in temperate and tropical climates.

Series XIV. Thalamifloræ.—Calyx usually of distinct sepals. Petals and stamens usually growing on the flower-receptacle. Ovary superior.

Malvale Cohort.

Order 126, the Lindens (Tiliaceæ); 330, trees, shrubs, rarely herbs. mostly tropical.

Order 127, the Sterculiads (Sterculiaceæ); 520, herbs, shrubs, and trees, almost entirely tropical.

Order 128, the Mallow-worts (Malvaceæ); 700, herbs, shrubs, and trees, widely distributed.

Guttiferale Cohort.

Order 129 (Chlænaceæ); 8, shrubs and trees of Madagascar.

Order 130 (Dipterocarpeæ); 112, resinous trees, rarely shrubs, of the tropics.

Order 131, the Theads (Ternstrœmiaceæ); 260, trees and shrubs, mostly tropical.

Order 132, the Guttifers (Guttiferæ); 230, resinous trees and shrubs of the tropics.

Order 133, the St.-John'sworts (Hypericaceæ); 210, herbs, shrubs, rarely trees, of warm temperate climates.

Order 134 (Elatinaceæ); 20, marsh-herbs, widely distributed.

Caryophyllale Cohort.

Order 135, the Tamarisks (Tamariscineæ); 40, mostly shrubs of the warm temperate zone.

Order 136, the Purslanes (Portulacaceæ); 125, herbs and a few small shrubs, widely distributed.

Order 137, the Pinkworts (Caryophyllaceæ); 800, herbs, widely distributed.

Order 138 (Frankeniaceæ); 12, maritime herbs and shrubs of warm temperate climates.

Polygalale Cohort.

Order 139 (Vochysiaceæ); 100, resinous trees and shrubs of tropical America.

Order 140, the Milkworts (Polygalaceæ); 400, mostly herbs of warm temperate climates.

Order 141 (Tremandreæ); 24, Australian shrublets.

Order 142 (Pittosporaceæ); 90, shrubs of hot climates.

Parietale Cohort.

Order 143 (Bixineæ); 160, trees and shrubs of the tropics.

Order 144 (Canellaceæ); 4, trees of tropical America.

Order 145, the Violets (Violaceæ), 240, herbs, shrubs, and a few trees of temperate and tropical climates.

Order 146, the Rock-roses (Cistaceæ); 60, herbs and shrubs of temperate climates.

Order 147, the Resedads (Resedaceæ); 30 to 40, herbs and a few shrubs, mostly of the Mediterranean region.

Order 148, the Capparids (Capparidaceæ); 300, herbs, shrubs, rarely trees, of tropical or subtropical regions.

Order 149, the Crucifers (Cruciferæ); 1200, herbs and a few low shrubs, widely distributed.

Order 150, the Fumeworts (Fumariaceæ); 100, herbs of warm temperate regions.

Order 151, the Poppyworts (Papaveraceæ); 60, herbs and a few low shrubs, mostly of the north temperate zone.

Order 152, the Pitcher-plants (Sarraceniaceæ); 8, American herbs.

Ranale Cohort.

Order 153, the Water-lilies (Nymphæaceæ); 35, aquatic herbs, widely distributed.

Order 154, the Berberids (Berberidaceæ); 100, herbs and shrubs of temperate climates.

Order 155, the Moonseeds (Menispermaceæ); 80, woody twining plants, mostly tropical.

Order 156, the Anonads (Anonaceæ); 400, trees and shrubs, mostly tropical.

Order 157, the Magnoliads (Magnoliaceæ); 70, trees and shrubs, mostly of warm climates.

Order 158 (Calycanthaceæ); 3, shrubs of North America and Japan.

Order 159 (Dilleniaceæ); 180, mostly shrubs, which are chiefly tropical.

Order 160, the Crowfoots (Ranunculaceæ); 540, herbs and a few shrubs of temperate and cool climates.

535. If we glance over the foregoing assemblage of plants, we are at once struck with their great diversity of structure, both as regards the flowers and the general plant-body. The extreme of simplicity is reached, perhaps, in the Podostemads; and these small aquatics, almost desti-

tute of fibro-vascular bundles and with minute flowers of simple structure, may be contrasted with the Heaths, Composites, and Madderworts. The highest development, all things considered, is undoubtedly reached in the Composites: this is indicated by the number and variety of their tissues, the high differentiation of the epidermal structures, the aggregation of their flowers into heads, and these often into secondary clusters; by the union of the parts of the flower; by its inferior ovary with its single ovule; its well-developed embryo; as well as by many other things which we have not space to explain here.

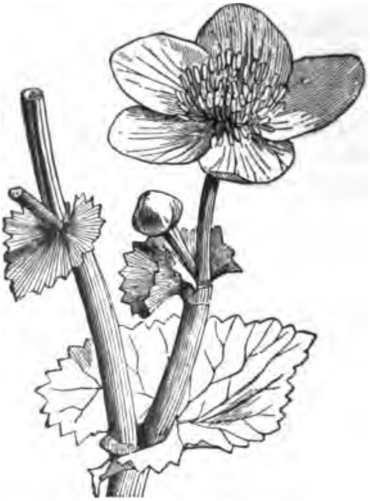

FIG. 143.—Marsh-marigold (Caltha palustris), with showy yellow perianth.

536. As to the arrangement of the Dicotyledons, it is probable that a natural disposition of the orders would place the Choripetalæ below the Gamopetalæ, the latter ex-

hibiting several divergent groups, the one containing the Asterale Cohort rising highest. In such an arrangement the orders of the Apetalæ would be placed as degraded or simplified offshoots mainly from the Choripetalæ, while a few would doubtless be regarded as directly lower than and preceding the latter group.

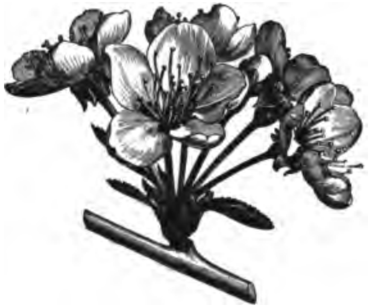

FIG. 144.—The Cherry (Prunus cerasus), with clustered flowers.

537. A great many Dicotyledons show adaptations for pollination by insect agency, and it is safe to say that more than half the species are more or less dependent upon the visits of insects in order that their ovules may be fertilized. In a general way it may be said that the showy flowers with a bright calyx or corolla, or both, are pollinated by insects, while those without showiness are wind-pollinated, or close-fertilized. The plants of the Apetalous orders are for the most part not visited by insects; few of them have bright colors, and few produce nectar.

538. The simpler Choripetalæ, as the Crowfoots (Fig. 143) and their near allies, attract insects by their showy perianth, and the nectar they secrete. Cross-fertilization is generally secured by a difference in the time of maturity of stamens and pistils (i.e., by dichogamy), apparently, however, often permitting close fertilization. The same is true in general of most of the regular flowered Choripetalæ. Thus in the Roseworts (Fig. 144), while nectar is usually abundant and the flowers are generally sweet-

scented as well as showy, their regularity of form prevents perfect cross-pollination. However, as the flowers are generally in clusters, it usually happens that the pollen from one flower is carried to the stigmas of another. The attractiveness of the flowers is such that through the visits of great numbers of insects the large amount of pollen is pretty well distributed upon other stigmas.

539. In the nearly related Leguminous Plants, as beans, peas, clover, lupines, etc., the perianth is not regular. There are three forms of petals in each flower, viz., one large broad one, the "banner," two lateral ones, the "wings," and two anterior ones which together form the "keel." These all together form a structure enclosing the stamens and pistil in such a way that an insect cannot get any of the nectar at the base of the corolla without setting free some of the pollen, which adheres to the hairs of its body and is thus carried to the stigma of some other flower.

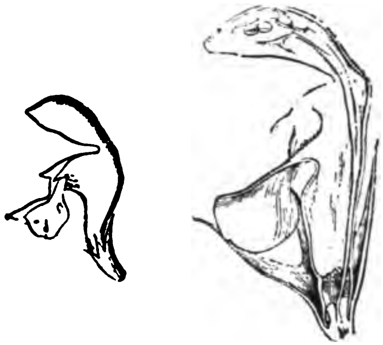

FIG. 145.—Flower of Dead-nettle, side view and vertical section. Magnified.

540. In the Gamopetalæ the union of petals into a tube serves to compel insects to visit the flower in one way only. In the Mints (Fig. 145) the flower is two-lipped, the broader

lip usually serving as a resting-place for the insect while it thrusts its head or tongue into the corolla. The upper lip is frequently arched so as to contain the stamens and style. In the Dead-nettle the stigma projects beyond the stamens (Fig. 145), so that upon visiting successive flowers the in-insect always first pollinates the stigma with pollen from preceding flowers, and then coming in contact with the stamens secures more pollen. In many plants with a similar structure the stamens mature before the stigmas are ready for pollination, so that in these, while the means for cross-pollination are perfect, self-fertilization is rendered impossible.

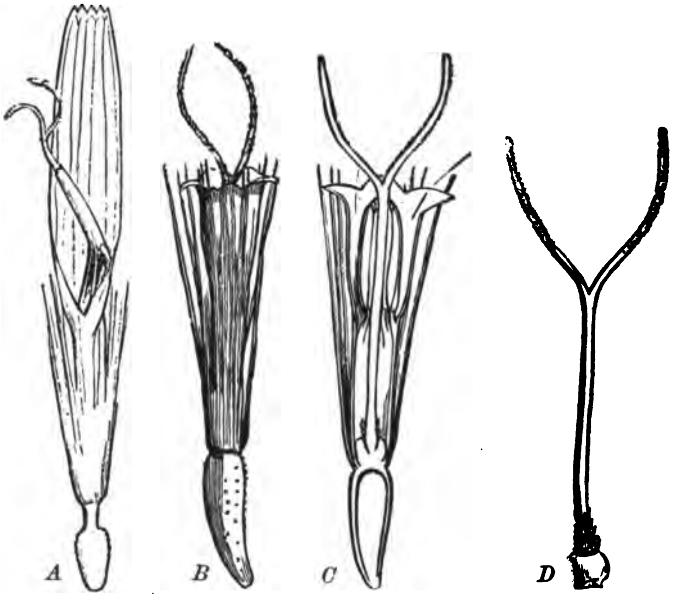

FIG. 146.—Flowers of Composites. *A*, of Dandelion, showing style protruding through ring of anthers; *B*, of Thoroughwort; *C*, ditto, vertical section showing style surrounded by anthers; *D*, style showing two stigmas. All magnified.

541. In the Compositæ (Fig. 146) the five anthers are united into a ring or tube around the style. The pollen escapes from the inner side of the anthers into the anther-tube, and at this time the immature style is short. As the latter grows it pushes up through the anther-ring, carrying the mass of pollen with it. Insects visiting the flowers for nectar at this stage rub off the little piles of pollen from the top of the stamen-tubes, and coming in contact afterwards with the expanded stigmas of other flowers, some of the pollen is left upon them.

542. After the pollen is set free the style elongates still more, and finally the two lobes of the stigma open out and are ready for pollination. This development takes place beginning at the outer rows of flowers in each flower-head and proceeds towards the centre. Thus at any time in any blooming flower-head, as of the Sunflower, there may be seen a ring of pollen-bearing flowers and outside of it a ring of flowers with expanded stigmas. In some Composites, in addition to these structural peculiarities, the stamens are sensitive, and when touched will suddenly contract, drawing the anther-tube down and ejecting pollen. This may easily be seen by passing the finger quickly across the top of a thistle-head when in full bloom.

543. The foregoing must serve to direct the student to the careful observation of the flowers of Dicotyledons. He should remember Lubbock's remark that "it is probable that all flowers which have an irregular corolla are pollinated by insects," and to this he may well add that it is equally probable that all tubular flowers are likewise pollinated by insects.

544. Among the interesting things to which attention has been directed during the past few years is that of the

insectivorous habits of certain plants. Here again no more than a fragment can be given, barely enough to introduce the student to the subject.

545. Many plants catch insects by means of their sticky glandular hairs, or glandular surfaces upon their stems or leaves. This may be readily seen by examining a petunia or tomato stem, or the sticky belts on the stems of various species of Catchfly, or the sticky spots on the bracts sur-

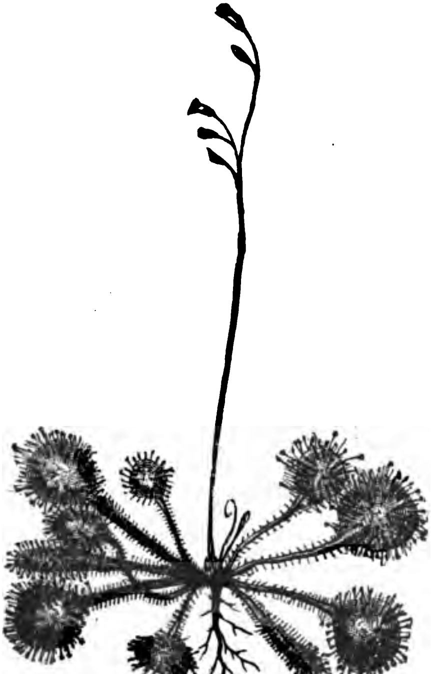

FIG. 147.—A Sundew plant. Natural size.

rounding the flower-heads of some thistles. Whether the small insects thus caught are made use of by the plants in any way is as yet uncertain.

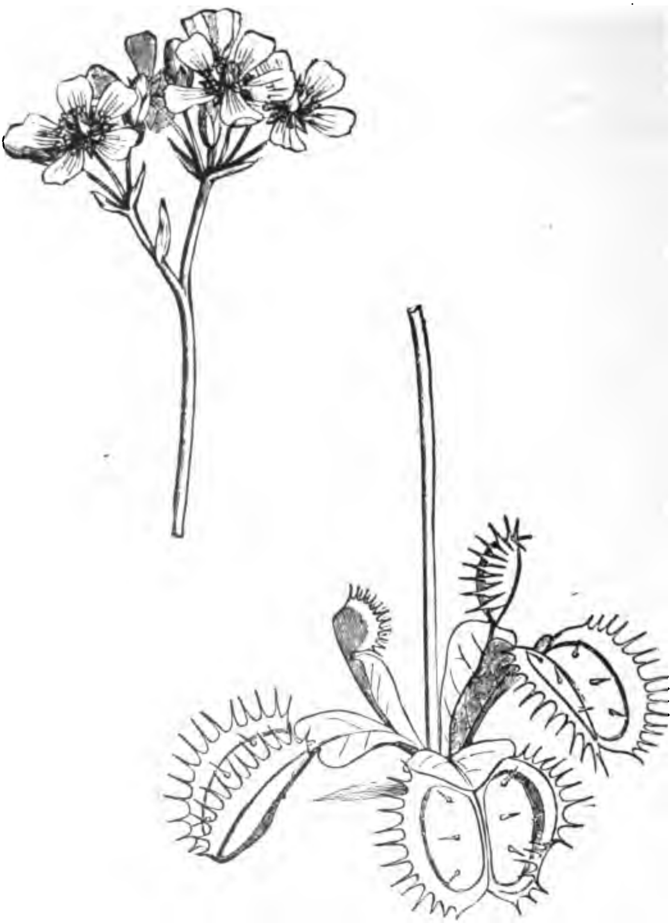

FIG. 148.—The Carolina Fly-trap (Dionæa muscipula). About natural size.

546. In the Sundews (Fig. 147), which are common little bog-plants, the leaves have many stalked glands which secrete a sticky substance. These glands are sensitive, and when an insect comes in contact with one or more of them and is held fast, the others slowly bend towards the insect, and the leaf itself rolls up, completely surrounding the unfortunate victim. An acid fluid is produced by the glands, and by this the insect is dissolved and afterwards absorbed by the leaf-tissues. In midsummer it is no uncommon thing to find several of these leaves with insects upon them.

547. The Carolina Fly-trap (Fig. 148), or Venus's Fly-trap as it is frequently called, is one of the most remarkable plants known. It is a native of a small district near Wilmington, North Carolina, but is now grown considerably as a curiosity in conservatories. Each leaf has a rounded blade fringed on the sides with a row of stiff points or spikes. Upon each half of the leaf there are generally three sensitive hairs, and when these are touched the sides quickly close together, and the stiff marginal spikes interlock like the teeth of a rat-trap. "The upper surface of the leaf is thickly studded with minute glands of a reddish or purplish color" (Darwin). These secrete an acid fluid which has the power of digesting insects and other nitrogenous matters. When an insect happens to alight upon a leaf and touches one of the sensitive hairs the trap closes so quickly upon it that it is almost invariably caught and securely held, its struggles only serving to increase the vigor of the grasp in which it is held. After a while the digestive fluid is poured out by the glands, and in this the insect is gradually dissolved. In this way the leaf-tissues absorb the insect, and are doubtless nourished

by it. After a time a leaf which has caught and digested an insect opens again and is ready for another. In this connection the student may profitably read Mr. Darwin's interesting book, "Insectivorous Plants," published in 1875.

548. A quite different class of insect-catching plants is represented by the Pitcher-plants of various kinds. In the Common Pitcher-plant, which grows in marshes in the Northern and Eastern United States, the leaves are dilated into tubular or pitcher-shaped cavities (Fig. 149), containing a watery fluid. The upper part of the leaf is reddish

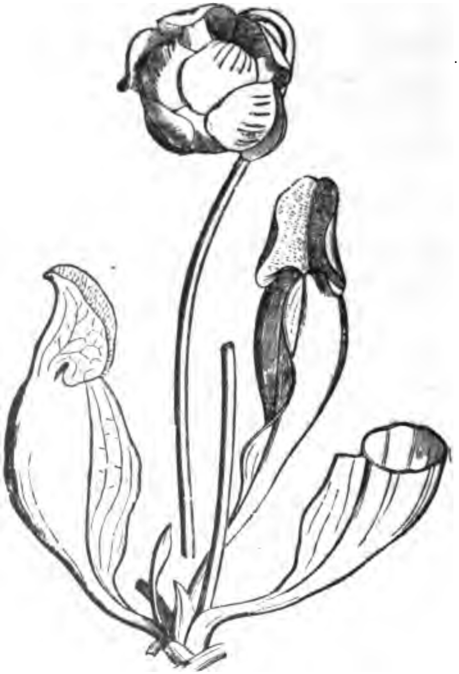

FIG. 149.—Common Pitcher-plant (Sarracenia purpurea), showing leaves and flower; one leaf cut across so as to show the cavity. Half natural size.

in color, and doubtless this attracts insects. Moreover this upper part is covered with minute stiff hairs, which point downward; they also cover the upper part of the inner surface of the cavity, and probably have not a little to do with the entrance of insects into the fatal pitcher. However this may be, many insects are found drowned, and in all stages of decomposition, in the fluid in the pitchers. Other species in the Southern States have a lid-like cover which prevents the entrance of rain, and in some species drops of nectar have been found upon the outside of the pitcher, forming a trail to lure insects to its edge.

549. The California Pitcher-plant (Fig. 150) resembles the foregoing, but its arched leaves have a curious forked appendage hanging down from the edge of the orifice, which is here on the under side of the arch. This appendage is more or less covered with a sweet secretion which lures insects. Probably this is made more effective by the reddish or purplish color of the appendage, giving it at a distance no little resemblance to a flower. The watery fluid inside of the leaf always contains the remains of many insects.

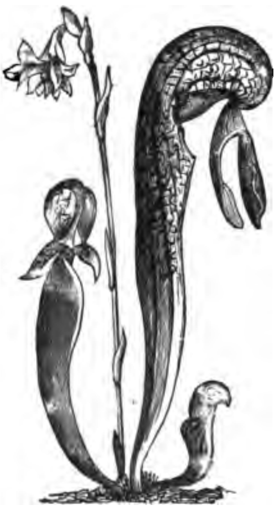

FIG. 150.—The California Pitcher-plant (Darlingtonia californica), showing leaves and a flower. About one seventh natural size.

550. Various species of Nepenthes (Fig. 151) occur in the East Indies. The leaves are prolonged into a slender tendril-like organ, upon whose extremity there develops a

hollow closed body, which finally becomes open by the separation of a hinged lid (Fig. 151, *d*, *e*, *f*). In the cavities of these pitchers a watery, slightly acid fluid is secreted;

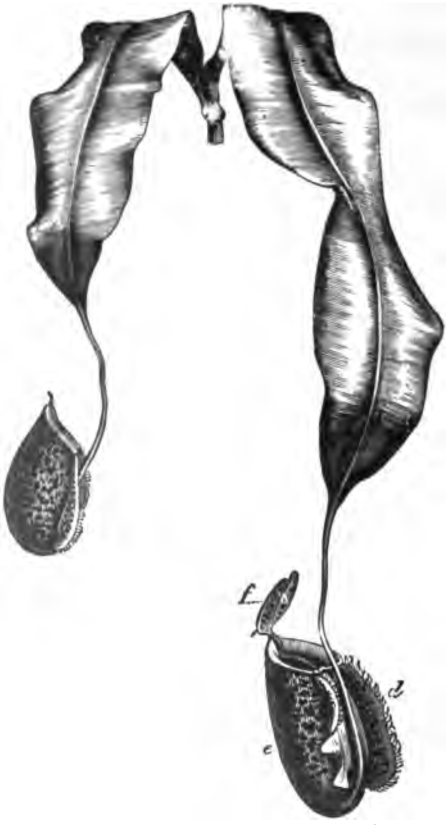

FIG. 151.—Two leaves of Nepenthes, the Indian Pitcher-leaf. *f*, the lid, which is still closed in the younger leaf. Reduced.

upon their borders are secreted honey or nectar drops, which attract insects, and these falling into the fluid within are soon dissolved by it, and then absorbed by the plant for its nourishment.

551. An Australian plant related to the Saxifrages produces remarkable pitchers. It is a low plant with a rosette of leaves upon the ground; some of these resemble the covered pipes used by many Frenchmen (Fig. 152). The border of the pitcher is incurved and presents an obstacle to the egress of insects, which are no doubt thus captured.

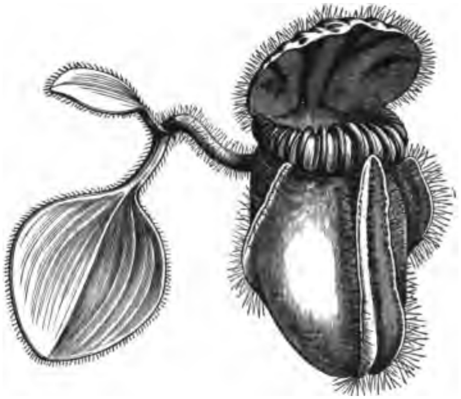

FIG. 152.—Leaves of Australian Pitcher-plant (Cephalotus). Natural size.

552. There is a close connection between the ornamental value of a plant and the perfection of its flower as a mechanism to secure pollination by means of insects. In other words, those things in a flower which are attractive to insects are, as a rule, attractive to us also. Thus the large, brightly-colored perianth and the sweet scent of the wild rose, which serve to secure the visits of insects, are likewise attractive to us.

553. The Apetalæ are thus of low ornamental value in so far as their flowers are concerned. The Gamopetalæ

and Choripetalæ, however, furnish many fine flowers which have long been favorite ornaments in gardens and conservatories. Thus the Verbenas, Phloxes, Heliotropes, Primroses, Azaleas, Rhododendrons, Heaths, Bellflowers, Honeysuckles, and great numbers of Composites may be taken to represent the ornamental members of the Gamopetalæ. And so the Passion-flowers, Roses, Lupines, Wistarias, Mallows, Camellias, Pinks, Violets, Mignonettes, Poppies, Water-lilies Buttercups, and Columbines may be taken as representatives of the ornamental Choripetalæ.

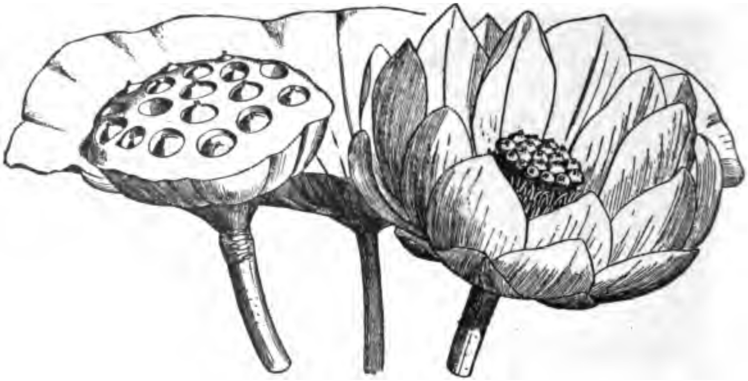

FIG. 153.—A Water-lily (Nelumbium luteum). One third natural size.

554. Economically the Apetalæ, Gamopetalæ, and the Choripetalæ are of very different rank. Thus while the first supplies us with very little food aside from the floury seeds of Buckwheat and the oily nuts of the Hickories, Walnuts, Hazels, Chestnuts, and a few others, it furnishes us the great bulk of our hard-wood timber in the wood of the Elms, Hackberries, Walnuts, Hickories, Oaks, Beeches, Chestnuts, Birches, Willows, Poplars, and Plane-trees. To

the Apetalæ also the world is indebted for that exceedingly valuable substance, India-rubber, which is obtained from the milky juice of several tropical trees related to the Nettles and the Spurges.

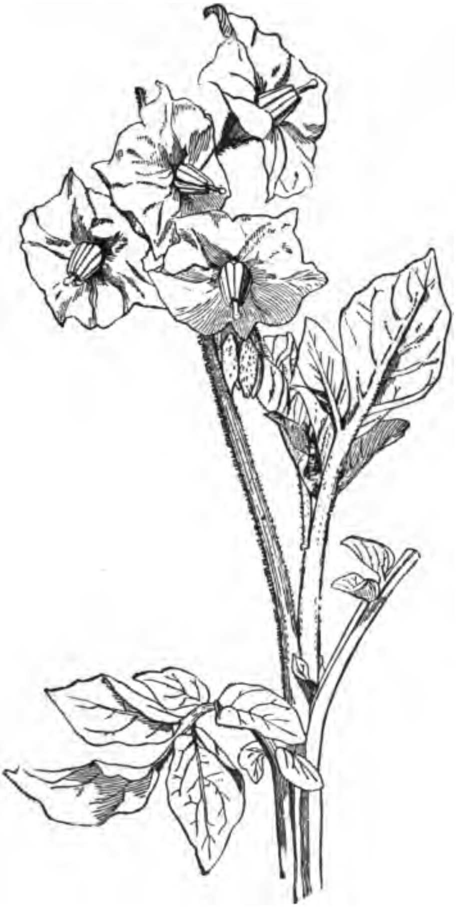

Fig. 154.—Potato.

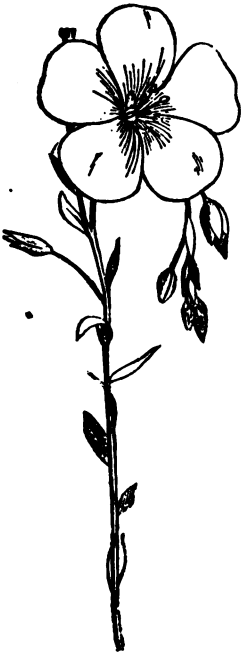

Fig. 155.—Flax.

555. The Gamopetalæ are of higher value as food-furnishers, supplying us with the Potato, Tomato, Sweet-potato, Artichokes, Olives, Huckleberries, Cranberries, Coffee. Of timber, the Catalpa, Ebony, and Ash are the more important of those in common use.

556. The Choripetalæ contain more plants which supply us with food than either of the preceding. Thus we have from these Parsnips, Carrots, Cucumbers, Melons, Squashes, Pumpkins, Apples, Pears, Strawberries, Blackberries, Raspberries, Plums, Peaches, Cherries, Beans, Peas, Grapes, Cabbage, Turnips, Radishes, and Tea. From this group we get flax and cotton, two of the most important fibres in the world. The timber-trees of most importance are the Maples and the Lindens, the Magnolias and the Tulip-trees.

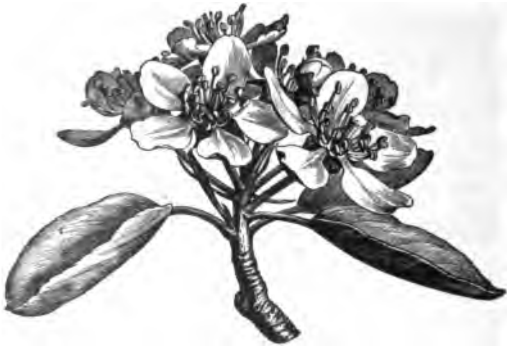

FIG. 156.—Flower-cluster of the Pear (Pirus communis).

557. The two drugs of greatest value medicinally, viz., opium and quinine, are furnished respectively by the Choripetalæ and Gamopetalæ.

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